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PROGRAM FOR DETERMINING..(U) GRUMMAN AEROSPACE CORP
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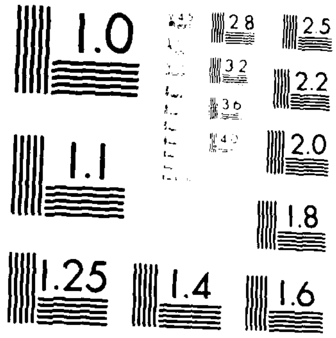
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REPORT NO. ADCR-85-1
Volume I

ESP — A PILOT COMPUTER PROGRAM FOR DETERMINING FLUTTER-CRITICAL EXTERNAL-STORE CONFIGURATIONS

VOLUME I - USER'S MANUAL

February 1985

Prepared Under Contracts N00019-81-C-0395
and N00019-84-C-0123

JOHN B. SMEDFJELD

GRUMMAN AEROSPACE CORPORATION
BETHPAGE, NEW YORK 11714

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

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for

NAVAL AIR SYSTEMS COMMAND
Washington, D.C. 20361

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FOREWORD

This report was prepared for the Naval Air Systems Command, Washington, D.C., under contracts N00019-81-C-0395 and N00019-84-C-0123, "Computer Code for Flutter-Critical External-Store Configurations". Funding was provided via Dr. Daniel Mulville, AIR-310B. The contract technical monitor was Mr. George Maggos, AIR-5302C.

The report consists of three volumes. Volume I, entitled "User's Manual", provides instructions for using the ESP program and presents descriptions of typical output. Volume II, "Final Report on Program Enhancement and Delivery", describes the work that was performed under the two contracts. A listing from a CDC compilation of the program is contained in Volume III, "Program Compilation".

The contributions of many individuals to the successful completion of the contracts are gratefully acknowledged. Ms. Ann Marie Novak performed much of the work required to convert the original IBM code to a CDC version. Highly valuable consulting support was provided by Mr. Richard Chipman, the primary developer of the original ESP version, and by Mr. Dino George and Dr. Joel Markowitz, key developers of FASTOP. Assistance on computing problems was provided by several persons at Grumman, including (in alphabetical order) Mr. Charles Bores, Mrs. Linda Ehlinger, Mr. Joel Halpert, Mr. Luke Kraner, Mr. Donald MacKenzie, Mr. Mario Mistretta, Mr. John Ortgiesen, Ms. Florence Hapfneimer, and Mrs. Noreen Woit. Key contributions to making the ESP program operational on the NADC Central Computing System were made by Messrs. Robert Richey and Howard Ireland of the Naval Air Development Center. Finally, Mr. Louis Mitchell of the Naval Air Systems Command provided valuable insight into program features which would be important to practicing flutter analysts, and also provided helpful suggestions during the preparation of this report.

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(continued)

1 - SUMMARY

A pilot computer program for determining flutter-critical external-store configurations has been developed and made operational on the Naval Air Development Center Central Computer System. The new program, designated ESP (External-Stores Program), is a derivative of the previously developed Flutter And STrength Optimization Program (FASTOP).

Three key ingredients in ESP are:

- o A p-k flutter-solution algorithm that includes an automated procedure for defining the flutter speed.
- o A calculation of the derivatives of the flutter speed with respect to the store parameters.
- o A gradient-directed numerical-search algorithm to seek out progressively lower flutter speeds within a parameter space defined by the range of store parameters at each aircraft store station.

A restart capability is available for continuing a search following a visual review of the search status after a run. Also, an analysis-only option permits a user to avoid the inclusion of input data required only for performing a store-parameter search. To facilitate the introduction of data required for the dynamic idealization of an aircraft, an automated interface has been developed between ESP and both the COSMIC and the MacNeal-Schwendler Corporation versions of NASTRAN.

The version of ESP that exists as of this writing was developed primarily with the objective of quickly evaluating the feasibility of the store-search concept. The program structure has not been optimized for minimum computing time, and not all options in the program have been checked. Thus, the current ESP version should be considered as a "pilot" code. Nevertheless, the unique capabilities of ESP have been shown to provide substantial advantages over previous approaches to the store-flutter problem. Therefore, this user's manual was prepared to permit early utilization of ESP on practical problems.

2 - INTRODUCTION

During the development of the initial version of the Flutter And STrength Optimization Program (FASTOP), Reference 1, under contract F33615-72-C-1101 from the Air Force Flight Dynamics Laboratory, Mr. Keith Wilkinson, the project engineer on that contract, recognized that much of the technology being used for minimum-weight structural resizing in FASTOP also had the potential for substantially reducing the time and cost required to determine which combinations of wing-mounted external stores would result in the lowest aircraft flutter speeds.

Subsequently, under contract N00019-76-C-0160 from the Naval Air Systems Command, as well as a complementary Grumman Independent Research and Development project, a search algorithm for wing/store flutter was developed, refined, and tested by modifying and expanding the FASTOP code (see References 2 and 3). When this development effort led to a pilot program that exhibited both good reliability (absence of search failure) and good convergence characteristics, work was continued under a second NASC contract, N00019-79-C-0062, to add features desirable for practical applications and to demonstrate the new External-Stores Program (ESP) on a representative attack aircraft and its associated store inventory (see Reference 4). The project engineer on these studies was Mr. Richard Chipman.

With the performance and the advantages of the store-search procedure having been confirmed, utilization of the procedure on current aircraft projects became desirable. To permit early availability of ESP to practicing flutter analysts, and to increase the applicability of the program to modern [illegible] aircraft with thinner, more flexible wings, the following additional [illegible] taken under contracts N00019-81-C-0395 and N00019-84-C-0123:

1) Several technical enhancements were introduced, including:
   - An increase from 20 to 40 in the maximum number of modes that can be calculated in a vibration analysis and used in a flutter analysis
   - Provision for including rigid-body modes

- o Logic for eliminating modes from a flutter analysis based on ratios of generalized forces to generalized masses
- o An increase from 6 to 15 in the maximum number of reduced velocities at which generalized aerodynamic forces are calculated and later used as a base for interpolation.

(2) Logic was added to by-pass data required for store-search runs if only a conventional flutter analysis is desired.

(3) The pilot code, previously available only as an IBM version, was converted to a CDC version compatible with the Central Computer System at the Naval Air Development Center. This included a substantial reduction in computer central-memory requirements.

(4) A capability was introduced for reading the dynamics-model input matrices either directly from NASTRAN output files or from card images.

(5) This user's manual was prepared.

To avoid unnecessary duplication, the content of this report complements and is intended to be used in conjunction with prior FASTOP and ESP reports. For descriptions of input data common to FASTOP and ESP, the reader is referred to Volume II of either Reference 1 or Reference 5. Theoretical documentation of the vibration- and flutter-analysis methods is contained in Volume I of Reference 1. Theoretical documentation of the store-search method is contained in Reference 4.

The version of ESP described in this report was developed for execution on computing equipment having extended-memory capability, and most of the information contained herein should be applicable to any such installation. However, the information on control cards in Section 4 is written specifically for the CDC equipment and NOS operation system at the NADC Central Computer

3 - PROGRAM OVERVIEW

The External-Stores Program (ESP) performs a gradient-directed numerical search to determine those combinations of external stores that are most flutter-critical for a given aircraft design and flight condition. The search is performed in a parameter space defined by a user-specified range of possible store properties (including both mass properties and on-diagonal pylon flexibilities, if desired) at each store station. A search step consists of a vibration-mode analysis, a flutter analysis, a calculation of the derivatives of the flutter speed with respect to the various store parameters, the determination of a new set of store parameters, and, to start the next search step, a modification of the system mass and flexibility matrices based on these new parameters. The search is started from a user-specified set of store parameters, and is continued until either a local minimum flutter speed is found or a user-specified number of search steps has been performed. If convergence to a minimum has not been achieved after the specified number of steps, a file containing recent values of key search parameters is saved to assist in continuing the search in a new job submission if desired. To expedite user assessment of the progress made during a search, an auxiliary output file is prepared, separate from the primary output to be printed, in which a summary is given of key parameters at each search step.

[illegible] VIBRATION-ANALYSIS MODULE

The vibration-analysis procedures in ESP are basically the same as those [illegible] Flutter And STrength Optimization Program (FASTOP) from which it was derived. However, the means of providing most of the dynamics-model input [illegible] ESP has been changed to facilitate the transfer of this information [illegible] programs other than the Strength Optimization Program (SOP) in [illegible]. Specifically, there is now a direct interface to ESP from both the [illegible] and the MacNeal-Schwendler Corporation (MSC) versions of NASTRAN for [illegible] flexibility matrix, two matrices containing the required mass data, and a [illegible] displacements in the dynamic degrees of freedom due to unit rigid-body displacements. A description of the steps required in a COSMIC or MSC NASTRAN run to obtain these matrices in an ESP-compatible form is given in [illegible] A. The dynamics-model input matrices may also be read into ESP as

card-image files, which could be created either manually or by a user-provided data-conversion program that is run following the execution of another upstream program.

Other ESP vibration-analysis-module changes from FASTOP include an increase in the maximum number of dynamics-model degrees of freedom (220 vs. [illegible]) and vibration modes (40 vs. 20). Also, as a user option, rigid-body mode shapes can be appended to the structural vibration modes for inclusion in the subsequent flutter analysis; the maximum total number of modes is also 40. To permit a limited degree of user control over rigid-body dynamic characteristics that cannot be modelled well or at all with the present capabilities of ESP (e.g., aerodynamics of nonconventional fuselage geometries, or flight-control-system effects), nonzero values may be specified for the zero-airspeed frequencies of the rigid-body modes. This capability will provide maximum [illegible] when used in conjunction with the capability in the flutter-analysis [illegible] (previously available in FASTOP) for specifying zero-airspeed modal [illegible] values. It is suggested that the input values be selected so that, [illegible]ined with the effects of the program-calculated aerodynamics, the [illegible] rigid-body characteristics at velocities close to the flutter speed are [illegible]. A discussion of the implementation of the rigid-body modal [illegible] in the ESP vibration-analysis module is contained in Appendix B.

[illegible] FLUTTER-ANALYSIS MODULE

[illegible] flutter-analysis procedures in ESP also are basically the same as [illegible] FASTOP, but again some significant changes have been introduced. [illegible] with the increase in the maximum number of modes in the vibration-[illegible], the corresponding number for the flutter-analysis module also [illegible] from 20 to 40. In addition, to address the much broader [illegible] reduced velocities that must be used when rigid-body modes are [illegible] flutter analysis, a change from 6 to 15 was made in the maximum [illegible] reduced velocities for which generalized aerodynamic forces may be [illegible] directly and later used as a base for interpolation. Related to [illegible], the generalized-force interpolation accuracy test described in [illegible], Volume II, pages 88 through 91, has been deleted, and the actual

number of reference reduced velocities to be used in a particular analysis is now a user-specified quantity.

Another flutter-analysis-module modification related to the capability to include rigid-body modes was a change to a two-zone generalized-force-interpolation method (one zone for high reduced velocities and one for low reduced velocities) in the flutter-solution procedures. With this approach, no values of the independent or dependent variable approach infinity for either very high or very low reduced velocities. This change is transparent to the user.

A new feature introduced into the flutter-analysis module is a capability for automatically eliminating from a p-k flutter solution any modes that would not significantly affect the predicted flutter characteristics. A mode is eliminated when the ratio of the modulus of the on-diagonal generalized-force term to the value of the corresponding generalized-mass term, is below a user-specified value of that ratio for each of three airplane forward velocities. Since the computing time used in the p-k solution is approximately proportional to the cube of the number of modes, and, for problems with many modes, the p-k solution time is a large percentage of the total time, utilizing this feature can significantly reduce computing expenditures.

SEARCH MODULE

Since the search objectives of ESP and FASTOP are very different, much of [illegible] the ESP flutter-optimization module is new. Flutter-velocity [illegible] are calculated for store mass, inertia, and center-of-gravity [illegible] and pylon flexibilities for up to five store stations, and a [illegible] numerical search technique is used to determine the location [illegible] the store-parameter/pylon-flexibility space at which the flutter [illegible] minimum. A detailed description of the ESP search procedure and [illegible] calculations is given in Reference 4, Sections 3 through 5.

[illegible]-ONLY OPTION

Although the objective of developing ESP was to provide an automated [illegible] procedure for determining flutter-critical combinations of external

[illegible], this program, like FASTOP, also may be used in a conventional analysis [illegible] if desired. By setting a single clue, program steps involving a search [illegible]-passed, and input data required for searches can be omitted.

[illegible] PROGRAM STATUS

[illegible] version of ESP documented in this report, although enhanced in [illegible] respects from the version that existed at the conclusion of the work [illegible] in Reference 4, must still be considered a "pilot" code. The program [illegible] has not been optimized for minimum computing time, and, for the most [illegible] those options actually used for the demonstration described in [illegible] have been checked. For the options that have not been checked, [illegible] that effect have been included as footnotes to the corresponding [illegible] descriptions in Subsection 5.2.

It is noted that the data description for FASTOP-3 given in Reference 5, Volume II, pages 224-307, is identical to the description in Reference 1 except for KLUE(8) in Item 6 of the main-program data, which, as specified below, is a dummy variable in ESP. Therefore, the following text may be used in conjunction with either of these references. To assist in cross-referencing, the page numbers in References 1 and 5 corresponding to each item or group of data have been listed in the following subsections immediately after their titles.

[illegible] Data Entered Via Main Program

(See also Reference 1, Volume II, pages 195-201, or Reference 5, Volume II, pages 224-229.)

Items 1-5 Identical to FASTOP.

Item 6	KLUE(1) - KLUE(6)	Identical to FASTOP.
	KLUE(7) = 0	Do not enter store-search module, i.e., perform analysis only.
	= 7	Perform store search. Requires that KLUE(3) = 3 and KLUE(4) = 4.
	KLUE(8) = 0	Dummy variable in ESP.
	KLUE(9) - KLUE(25)	Identical to FASTOP.
	KLUE(26) = 0	Dummy variable in ESP.
	KLUE(27) = 27	Fixed value in ESP.
	KLUE(28) = [illegible]	Fixed value in ESP.
	KLUE([illegible]) - KLUE(3[illegible]) = [illegible]	Dummy variables in ESP.
	KLUE([illegible]) = [illegible]	Fixed value in ESP.
	KLUE(35) - KLUE(36) = 0	Dummy variables in ESP.

o The first data group on each card should be nonblank; one or both of the other two may be blank.

A few additional comments on the dynamics-model matrices follow. First, it is noted that the modal-interpolation procedure in the flutter-analysis module requires that the input modal data be specified at points along a set of spanwise-oriented lines (see Reference 1, Volume I, page 8[illegible]). Therefore, the dynamics idealization used to create the input matrices to the vibration-analysis module should be defined with this requirement in mind.

Second, the vibration-analysis module in ESP cannot accommodate a singular mass matrix. Therefore, the masses at all dynamics-model grid points must be nonzero, and, at those grid points for which rotation degrees of freedom are used, the corresponding moments of inertia also must be nonzero.

Finally, when NASTRAN is used to define the ESP dynamics-model matrices, the matrices to be passed (using the procedures described in Appendix A) are those corresponding to the "analysis" (or "solution") set. Therefore, the NASTRAN idealization used must be such that the store degrees of freedom are independent coordinates.

[illegible] PRIMARY INPUT-DATA FILE

Since the input data to ESP is to a considerable extent similar to that specified for FASTOP in Reference 1, Volume II, pages 195-279, the primary emphasis in the text below is on data which is new for ESP. To avoid unnecessary repetition, large blocks of descriptive information for FASTOP which are the same for ESP, or are not used in ESP, are simply described as such. To facilitate cross-referencing, the data-item numbers in Reference 1 have been retained below. When a data item that was previously used in FASTOP has been modified for use in ESP, the associated variable list and description below should be considered to replace the information in Reference 1. For some FASTOP items that have been retained unchanged in ESP, a new definition has been given to provide further clarification. For data items new for ESP, new item numbers have been created by appending letters to immediately preceding FASTOP item numbers.

follow the dynamic mass matrix in input file TAPE25. In the single input file used for COSMIC-NASTRAN matrices (TAPE20), the following order must be adhered to: flexibility matrix, mass matrix, rigid-body-displacement matrix, plug mass matrix. Additional specific instructions for writing the NASTRAN files are contained in Appendix A.

When the dynamics-model matrices are provided in card-image form, the following data-preparation instructions may be followed for all three matrices:

- The Fortran format should be (3(2I4,E15.5,1X)). Each group of three numbers in this format consists of a row number, a column number, and an element value.
- All matrix elements should be provided.
- The elements should be in consecutive order by row.
- The first element of each row should constitute the first data group on a new card.
- Each card, except that containing the last element in each row, should have a full complement of three data groups.
- The cards containing the matrix elements should be followed by a blank card.

If desired, the instructions just listed may be relaxed for individual matrices as follows:

- Flexibility matrix:
  - The row and column numbers are optional; i.e., the format may be (3(8X,F15.5,1X)).
  - A final blank card is not required.
- Mass matrix:
  - All nonzero matrix elements must be provided.
  - Any of the three data groups on a card may be blank, but each card except the last (blank) card should have at least one data group.
  - The first element specified for each row should be on a new card.
- Rigid-body-displacement matrix:
  - All nonzero matrix elements must be provided.
  - There is no element-ordering requirement.

performed, the initially arbitrary values are replaced by new values computed within ESP based on data provided in the primary input-data file (see Items 8C-8F in Subsection 5.[illegible]). Subsequently, these values are updated as the search proceeds.

In an analysis-only run, the input data used for searches, which includes the starting store-mass and pylon-flexibility values, is not read. Therefore, in this case, the mass and flexibility matrices must contain the store-mass and pylon-flexibility parameters that are desired for that run. Also, since [illegible] are not [illegible] within ESP in an analysis-only run, adherence [illegible] coordinate system in Figure 5-1 is not mandatory for [illegible] degrees of freedom that are passed to the flutter analysis model.

The maximum number of dynamic degrees of freedom that currently can be [illegible] in ESP is [illegible], not including the plug motions. Thus, the [illegible] maximum number of rows and columns in the flexibility and mass matrices, and the maximum number of columns in the rigid-body-displacement matrix.

[illegible] of the four dynamics-model matrices should be as follows:

[illegible] flexibility matrix: in./lb., in./lb.-in.

rad./lb., rad./lb.-in.

[illegible] matrix: [illegible], lb.-in., lb.-in.^{2}

[illegible]

[illegible] matrix: in./in., in./rad., rad./rad.

As stated previously in Section 4, the four dynamics-model matrices [illegible] into ESP via from one to three data files. The format of the [illegible] either that provided by the OUTPUT2 routine in the COSMIC NASTRAN, that provided by the OUTPUT4 routine in the [illegible] Corporation (MSC) version of NASTRAN, or a card-image [illegible] described below. To a great extent, the source of each of the four [illegible] (i.e., COSMIC-NASTRAN, MSC-NASTRAN, or card-image files) can be [illegible] of the source of each of the others. However, both mass matrices [illegible] the same source, and, if any matrices are obtained from COSMIC [illegible], the flexibility matrix must be from COSMIC NASTRAN. When the source [illegible] matrices is MSC NASTRAN or card images, the plug mass matrix must

in the inboard direction, and positive M_x is associated with upward vertical displacement of the left side. These modifications produce a sign change in all off-diagonal terms in the sixth row and column of Eqs. (4-2) through (4-5) of Reference 4. The degrees of freedom that should adhere to the coordinate system in Figure 5-1 are primarily those that are used at the pylon/store attachment points. However, for a wing represented structurally as a beam, the degrees of freedom that are used for modal interpolation in the flutter-analysis module should be defined such that nose-up rotation in pitch is considered positive when downward vertical displacement is positive.

When a store-parameter search is being performed, certain elements in the flexibility and mass matrices that are supplied to ESP may be arbitrary. For the flexibility matrix, the on-diagonal elements associated with the store degrees of freedom are arbitrary, and, for the mass matrix, all store-degree-of-freedom elements are arbitrary. Before the first vibration analysis is

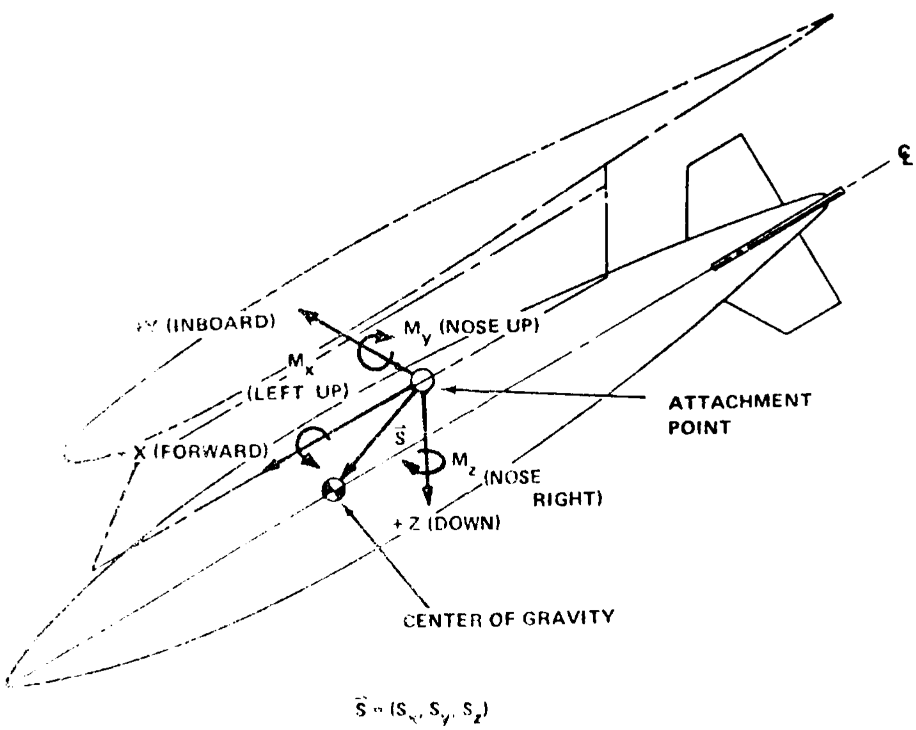

Figure 5-1 - Store Dynamic Coordinate System

5 - INPUT-DATA DESCRIPTION

5.1 - DYNAMICS-MODEL DATA FILES

As indicated in the previous section, there are four dynamics-model matrices that must be provided to ESP from an external source:

- A flexibility matrix. This has been called KLLI in the illustrative NASTRAN DMAP alter statements shown in Appendix A in Figures A-2 and A-4.
- A mass matrix associated with the dynamic degrees of freedom other than those that are assumed to be fixed when computing the flexibility matrix. For brevity, this matrix will hereinafter be referred to simply as the dynamic mass matrix or mass matrix. The NASTRAN name used for this matrix in the DMAP alter statements in Figures A-2 and A-4 is MLLW.
- A separate mass matrix for the degrees of freedom at the assumed free-body support points. Following the terminology in Reference 1, Volume I, Section 7, pages 48 and 49, this will hereinafter be referred to as the "plug" mass matrix. The name MRRW has been used for this matrix in the illustrative DMAP alter statements cited above.
- A matrix containing displacements in the dynamic degrees of freedom due to unit rigid-body displacements at the free-body support point or plug. This matrix is called DM in both the COSMIC and MSC versions of NASTRAN Rigid Format 3.

[illegible] matrix, as read in ESP, is arranged such that the displacements in the various dynamic degrees of freedom due to each unit rigid-body displacement occupy one row of the matrix. The rows should be ordered such that rigid-body translation modes precede rigid-body rotation modes. The [illegible] this matrix is the λ_D submatrix in Eq. (7.15) of the reference [illegible] above.

The dynamics-model matrices should apply to a half-airplane, and, for [illegible] degrees of freedom, should be developed following the coordinate [illegible] shown in Figure 5-1. This coordinate system is a variation of that [illegible] Figure 4-1 of Reference 4: To permit utilization of matrices from [illegible], which are based on a right-hand coordinate system, Y is now positive

As a final comment on the illustrative control-statement sequences, it is noted that the implied judgment concerning which files are to be considered direct-access and which are indirect-access should be used for initial guidance only. Also, where there is a significant possibility that a file could be in either category, depending upon its contents for a particular application, the direct-access option has been selected. This is especially applicable to TAPE24, the mass-matrix file. If this matrix is obtained from MSC NASTRAN, it can probably be considered as indirect-access, whereas, if it is in card-image form, it might have to be direct-access.

TAPE08 is a composite of up to 15 files which contain aerodynamic-influence-coefficient matrices (see note 1 on page 4-5) calculated at a specific Mach number for the reference reduced velocities. In the illustrative control-statement sequence for an analysis run, shown in Figure 4-1, AIC's are being created and saved, and, in the two search runs, shown in Figures 4-2 and 4-3, these AIC's are being used. The creation of AIC's in a separate initial analysis run, rather than as part of a search run, is generally recommended, since, in a search run, the AIC's would be unnecessarily recreated during each step in the search. As a further measure to conserve computing time, it is suggested that the initial analysis run utilize the k method for the flutter solution rather than the p-k method. A quantitative indication of the savings to be realized from these guidelines can be obtained from Table 4-1.

The fifth possible input file, read via TAPE47, is used only when restarting (see Figure 4-3). This file would have been created via TAPE48 as an output file from a prior search or restart run. Additional information on this file is contained in Subsection 6.3, beginning on page 6-24.

Up to four output files may be created and saved via ESP. In addition to the AIC file and the restart file which have already been discussed, there is also a file for obtaining plots of the flutter-analysis results, and a file containing a summary of key parameters at each step of a search. The latter is obtained via TAPE40 as illustrated in Figures 4-2 and 4-3. In most cases, a quick interactive review of this file will permit a search to be restarted with confidence if required.

The plot file, which may be obtained from any search or analysis run, is written via TAPE60. In a search run, the plot file contains the plotting output for all flutter analyses performed during the search. The conversion of the plot file to actual hard-copy plots using an NADC CalComp plotter is accomplished via a manually completed request form. Therefore, this step requires the assistance of an on-site NADC person.

The two parameters on the ACCOUNT cards are a user number and a password, which should be requested as described on page 1-22 of Reference 6.

An absolute file of the ESP program is accessed via the first ATTACH card. The four digits in the file name designate the version of the program in terms of the year and the month in which it was created. The six-digit second parameter on the program ATTACH card designates the user number under which the program absolute file is stored. The third parameter is the associated password. Navy personnel wanting to run ESP at NADC may obtain the last two parameters by contacting Mr. Robert Richey, Code 60412, Naval Air Development Center, Warminster, PA 18974, (215) 441-1944.

Input data to ESP consists of a user-prepared card-image file read via TAPE16, plus up to five additional files depending on the options specified in the TAPE16 file. From one to three of these files - read via TAPE20, TAPE25, and TAPE26 - contain four matrices which together constitute most of the data needed to define the analytical model of the airplane dynamics. These are: a flexibility matrix, a mass matrix associated with the dynamic degrees of freedom other than those that are assumed to be fixed when computing the flexibility matrix; a separate mass matrix for the degrees of freedom at the assumed free-body support point; and a matrix containing displacements in the dynamic degrees of freedom due to unit rigid-body displacements at the free-body support point. Each of these matrices may be read into ESP in a form consistent with output from NASTRAN (either the COSMIC or the MacNeal-Schwendler Corporation (MSC) version), or they may be read as card-image files. Matrices obtained from COSMIC NASTRAN are all read via TAPE20. MSC-NASTRAN matrices or card-image matrices are read as follows: the flexibility matrix via TAPE20, the two mass matrices via TAPE25, and the rigid-body displacement matrix via TAPE26. In the illustrative control-statement sequences shown in Figure 4-1 through 4-3, it has been assumed that all matrices are coming from COSMIC NASTRAN, and therefore only TAPE20 is active. For MSC-NASTRAN or card-image matrices, the statements that have been commented out with asterisks would be activated in place of the currently active COPY statement.

Table 4-1

Typical Central-Processor Times for Major Components of an ESP Execution Run

Function	Problem Size	Cyber 760 CP Time (dec. secs.)
Vibration analysis	200 degrees of freedom 40 flexible modes	90
Compute and save double-lattice aerodynamic influence coefficients (AIC's)[1] and compute generalized forces	60 panels 15 reduced velocities 8 modes	60
Use previously saved AIC's[1] to compute generalized forces	60 panels 15 reduced velocities 8 modes	6
k-method flutter solution	20 reduced velocities 8 modes	1
p-k method flutter solution[2]	40 velocities[3] 8 modes	70
p-k method flutter solution[2]	40 velocities[3] 40 modes	6000
p-k method flutter solution[2]	12 velocities[4] 40 modes	3400
Derivative calculation and search step	200 degrees of freedom 8 modes 6 store parameters	1

---

[1] Quantities saved are not AIC's but intermediate results of the solution procedure (see Reference 7, pages 34-35).

[2] [illegible] calculations of derivatives of generalized forces with respect to reduced frequency.

[3] [illegible] first step in search.

[4] [illegible] subsequent search steps.

```
ESPRUNR,TXXXX,CM300000,EC70,STP00.
ACCOUNT,UUUUUU,PPPPPPP.
RFL,EC=70.
ATTACH,ABS=ESP8501/UN=NNNNNN,PW=WWWWWWW.
ATTACH,TAPE08=AAAAAAA.
GET,TAPE16=DDDDDDD.
ATTACH,TAPE20=CCCCCCC.
*ATTACH,TAPE20=FFFFFFF.
*ATTACH,TAPE25=MMMMMMM.
*GET,TAPE26=TTTTTTT.
GET,TAPE47=IIIIIII.
DEFINE,TAPE60=GGGGGGG.
COPYBF,TAPE08,FL0801A.
COPYBF,TAPE08,FL0802A.
COPYBF,TAPE08,FL0803A.
COPYBF,TAPE08,FL0804A.
COPYBF,TAPE08,FL0805A.
COPYBF,TAPE08,FL0806A.
COPYBF,TAPE08,FL0807A.
COPYBF,TAPE08,FL0808A.
COPYBF,TAPE08,FL0809A.
COPYBF,TAPE08,FL0810A.
COPYBF,TAPE08,FL0811A.
COPYBF,TAPE08,FL0812A.
COPYBF,TAPE08,FL0813A.
COPYBF,TAPE08,FL0814A.
COPYBF,TAPE08,FL0815A.
REWIND,FL0801A,FL0802A,FL0803A,FL0804A,FL0805A,FL0806A.
REWIND,FL0807A,FL0808A,FL0809A,FL0810A,FL0811A,FL0812A.
REWIND,FL0813A,FL0814A,FL0815A.
ABS.
SAVE,TAPE40=SSSSSSS.
SAVE,TAPE48=OOOOOOO.
```

Figure 4-3 - Typical Control-Card Sequence for Search-Restart Run Using Previously Saved Aerodynamic Influence Coefficients.

```
ESPRUNS,TXXXX,CM300000,EC70,STP00.
ACCOUNT,UUUUUU,PPPPPPP.
RFL,EC=70.
ATTACH,ABS=ESP8501/UN=NNNNNN,PW=WWWWWWW.
ATTACH,TAPE08=AAAAAAA.
GET,TAPE16=DDDDDDD.
ATTACH,TAPE20=CCCCCCC.
*ATTACH,TAPE20=FFFFFFF.
*ATTACH,TAPE25=MMMMMMM.
*GET,TAPE26=TTTTTTT.
DEFINE,TAPE60,GGGGGGG.
COPYBF,TAPE08,FL0801A.
COPYBF,TAPE08,FL0802A.
COPYBF,TAPE08,FL0803A.
COPYBF,TAPE08,FL0804A.
COPYBF,TAPE08,FL0805A.
COPYBF,TAPE08,FL0806A.
COPYBF,TAPE08,FL0807A.
COPYBF,TAPE08,FL0808A.
COPYBF,TAPE08,FL0809A.
COPYBF,TAPE08,FL0810A.
COPYBF,TAPE08,FL0811A.
COPYBF,TAPE08,FL0812A.
COPYBF,TAPE08,FL0813A.
COPYBF,TAPE08,FL0814A.
COPYBF,TAPE08,FL0815A.
REWIND,FL0801A,FL0802A,FL0803A,FL0804A,FL0805A,FL0806A.
REWIND,FL0807A,FL0808A,FL0809A,FL0810A,FL0811A,FL0812A.
REWIND,FL0813A,FL0814A,FL0815A.
ABS.
SAVE,TAPE40=SSSSSSS.
SAVE,TAPE48=OOOOOOO.
```

Figure 4-2 - Typical Control-Card Sequence for Initial Search Run Using Previously Saved Aerodynamic Influence Coefficients.

```
ESPRUNA,TXXXX,CM300000,EC70,STP00.
ACCOUNT,UUUUUU,PPPPPPP.
RFL,EC=70.
ATTACH,ABS=ESP8501/UN=NNNNNN,PW=WWWWWWW.
GET,TAPE16=DDDDDDD.
ATTACH,TAPE20=CCCCCCC.
*ATTACH,TAPE20=FFFFFFF.
*ATTACH,TAPE25=MMMMMMM.
*GET,TAPE26=TTTTTTT.
DEFINE,TAPE08=AAAAAAA.
DEFINE,TAPE60=GGGGGGG.
ABS.
REWIND,FL0801A,FL0802A,FL0803A,FL0804A,FL0805A,FL0806A.
REWIND,FL0807A,FL0808A,FL0809A,FL0810A,FL0811A,FL0812A.
REWIND,FL0813A,FL0814A,FL0815A.
COPYBF,FL0801A,TAPE08.
COPYBF,FL0802A,TAPE08.
COPYBF,FL0803A,TAPE08.
COPYBF,FL0804A,TAPE08.
COPYBF,FL0805A,TAPE08.
COPYBF,FL0806A,TAPE08.
COPYBF,FL0807A,TAPE08.
COPYBF,FL0808A,TAPE08.
COPYBF,FL0809A,TAPE08.
COPYBF,FL0810A,TAPE08.
COPYBF,FL0811A,TAPE08.
COPYBF,FL0812A,TAPE08.
COPYBF,FL0813A,TAPE08.
COPYBF,FL0814A,TAPE08.
COPYBF,FL0815A,TAPE08.
```

[illegible] -- Typical Control-Card Sequence for Analysis-Only Run in Which Aerodynamic Influence Coefficients Are Calculated and Saved.

4 - CONTROL CARDS

Execution of ESP on the Central Computer System at the Naval Air Development Center can be accomplished using NOS control-card sequences similar to those shown in Figures 4-1 through 4-3. The first figure illustrates an analysis-only submission in which aerodynamic influence coefficients (AIC's) are to be calculated and saved. The second figure illustrates a search run utilizing previously saved AIC's, and the third figure shows a restart of a search run. The last letter of the job name on the JOB control cards in these figures was chosen as an identifier for each of the three types of runs. The control cards for a fourth type of submission - an analysis-only run using previously saved AIC's - would be the same as those shown in Figure 4-2 except that the last two cards may be omitted.

The central-processor time-limits on the JOB cards for submissions to the NADC Central Computer System should be specified in terms of decimal seconds on the CDC 6600. Appropriate adjustments for job executions on the Cyber 175 or Cyber 760 are performed within the system. (The additional control cards specified on pages 3-2-8 of Reference 6 should no longer be used.) To assist the user in making initial time estimates, some approximate times for the major components of an ESP run are listed in Table 4-1. The times are given in terms of Cyber 760 seconds because this provides a more immediate indication of the practicality of a particular type of run with the computing equipment available. A conversion factor of 3.7 between Cyber 760 time and 6600 time is suggested on page 3-2-8 of Reference 6.

The second parameter on the JOB cards specifies the maximum amount of central memory needed for ESP in terms of octal words. This is followed by the requirement for extended memory, given as the maximum octal number of 1000_8 words. The actual request for extended memory is accomplished via the RFL command, which is the third control card shown in Figures 4-1 through 4-3. The final parameter on the JOB cards specifies execution under the NOS operating system at an "economy" charging rate as described on page 1-20 of Reference 6. The "P0" priority (deferred execution) that results from the use of this parameter is required for ESP by virtue of its central-memory usage and the restrictions given in Figure 3-2-1 on page 3-2-8 of Reference 6.

Item 6 (cont.)	KLUE(37) = 0	Cantilever-wing vibration analysis to be performed in AVAM.[1]
	= 37	Free-free vibration analysis to be performed in AVAM.
	KLUE(38) = 0	Do not include rigid-body modes in AVAM output passed to AFAM.
	= 38	Include rigid-body modes in AVAM output.
		KLUE(38) is ignored by the program if KLUE(37) = 0.

Format and comments on alternative approaches to entering above data are identical to FASTOP.

5.2.3 Data Entered Via Vibration-Analysis Module

(See also Reference 1, Volume II, pages 202-216, or Reference 5, Volume II, pages 230-244.)

Items 1-2 Identical to FASTOP.

Item 3	KLUEV(1) = 0	Fixed value in ESP and FASTOP.
	KLUEV(2) = 0	Do not plot vibration modes.
	= 2	Plot vibration modes on CalComp.[1,2]
	KLUEV(3) = 0	Do not list flexibility matrix as used in eigenvalue solution.
	= 3	List flexibility matrix.
	KLUEV(4) = 0	Do not list transformed mass matrix as used in eigenvalue solution.
	= 4	List transformed mass matrix.
	KLUEV(5) = 0	Dummy variable in ESP.
	KLUEV(6) = 0	Dummy variable in ESP.
	KLUEV(7) = 0	Do not list flexibility matrix as obtained from NASTRAN or card-image file.
	= 7	List input flexibility matrix.

---

[1] Not checked in ESP.

[2] Generally limited to analysis-only runs.

Item 3 (cont.)	KLUEV(8) = 0	Do not list dynamic mass matrix as obtained from NASTRAN or card-image file.
	= 8	List input dynamic mass matrix.

The rigid-body-displacement matrix and the plug mass matrix are always printed as they are read.

The format for the above data, and comments on alternative approaches to entering these data, are identical to FASTOP.

Item 3A	NDYDOF	Number of dynamic degrees of freedom (excluding plug degrees of freedom). Maximum value is 220.
	IDYFLX = 0	Dynamic flexibility matrix is provided as card-image data according to the format and instructions given in Subsection 5.1.
	= 1	Dynamic flexibility matrix is provided in the nonsparse binary format obtained from the OUTPUT4 routine in the MacNeal-Schwendler version of NASTRAN.[†]
	= 2	Dynamic flexibility matrix is provided in the format obtained from the OUTPUT2 routine in the COSMIC version of NASTRAN.[†]
	IMASS = 0	Dynamic mass matrix and plug mass matrix are provided as card-image data according to the format and instructions given in Subsection 5.1.
	= 1	Dynamic mass matrix is provided in the sparse binary format obtained from the OUTPUT4 routine in the MacNeal-Schwendler version of NASTRAN. Plug mass matrix is provided[†] in the nonsparse binary format from OUTPUT4.[†]
	= 2	Dynamic mass matrix and plug mass matrix are provided in the format obtained from the OUTPUT2 routine in the COSMIC version of NASTRAN.[†]

---

† See Appendix A for additional descriptive and illustrative material on the NASTRAN/ESP interface.

Item 3A (cont.)	ITRNSF = 0	Matrix of displacements in dynamic degrees of freedom due to unit rigid-body displacements is provided as card-image data according to the format and instructions given in Subsection 5.1.
	= 1	Rigid-body displacement matrix is provided in the nonsparse binary format obtained from the OUTPUT4 routine in the MacNeal-Schwendler version of NASTRAN.[1]
	= 2	Rigid-body displacement matrix is provided in the format obtained from the OUTPUT2 routine in the COSMIC version of NASTRAN.[1]

Format = (4I5). Number of cards is 1.

Data are entered by subroutine READY.

Items 4-8 FASTOP logic/data items not used in ESP.

Item 8A Logic Item - No Data

If a store search is to be performed (KLUE(7) = 7), continue with instructions below. Otherwise (KLUE(7) = 0), go to Item 16.

Repeat items 8B - 8I for each store station. Then add a blank card. Maximum number of store stations is 5.

The store-mass parameters entered as Items 8C - 8F will be used in the program to replace the appropriate elements of the mass matrix provided as a separate data file (see Subsection 5.1). Similarly, the flexibility values entered as Item 8F will replace elements of the flexibility matrix provided as a separate data file. The elements in these matrices that will be replaced are determined by the degrees of freedom entered as Item 8H.

When restarting a search, Items 8C - 8F should be the values corresponding to the point in the store-parameter space from which the next series of search steps is to begin. These are obtained from the output at the end of the previous series of search steps (see Subsection 6.3).

---

[1] See Appendix A for additional descriptive and illustrative material on the NASTRAN/ESP interface.

Item 8B IDSTR Store-station number. Must be one of a sequence from 1 to the total number of stores. Maximum value is 5.

Format = (I5). Number of cards is 1.

Data are entered by subroutine READY.

Item 8C STRWI Initial store weight in store-search run, lb.

Format = (E15.5). Number of cards is 1.

Data are entered by subroutine READY.

Item 8D STRII(K), K=1,3 Initial store moments of inertia about local x, y, and z axes through store center of gravity, lb.-in.^{2}

Format = (3E15.5). Number of cards is 1.

Data are entered by subroutine READY.

Item 8E STRRI(K), K=1,3 Initial store center-of-gravity x, y, and z offsets relative to store dynamic degree-of-freedom location (nominal store/pylon attachment point), positive for store center-of-gravity location forward, inboard, and below pylon attachment point, in. As discussed further in Subsection 5.1, this represents a change from the convention used in Reference 4.

Format = (3E15.5). Number of cards is 1.

Data are entered by subroutine READY.

Item 8F STRSI(K), K=1,6 Initial flexibility-matrix diagonal elements for translations in x, y, and z directions and rotations about x, y, and z axes at nominal store/pylon attachment point, in./lb. or rad./lb.-in.

These elements are incremented within the program when pylon-flexibility parameters are search variables. If a flexibility-matrix element is entered here as zero, the initial search value of that element will be the one contained in the flexibility matrix provided as a separate data file (see Subsection 5.1).

Format = (6E10.3). Number of cards is 1.

Data are entered by subroutine READY.

Item 8G	ISTDOF(K) = 0, K=1,6	Dummy variable in ESP.

Format = (6I5). Number of cards is 1.

Data are entered by subroutine READY.

Item 8H	IDYDOF(K),K=1,6	Dynamic degree-of-freedom numbers corresponding to translations in x, y, and z directions and rotations about x, y, and z axes at nominal store/pylon attachment point. If an airplane dynamics model does not include degrees of freedom for one or more of the 6 store displacement components, enter zero for those components.

Format = (6I5). Number of cards is 1.

Data are entered by subroutine READY.

Item 8I	SCALEW	Factor to be used to scale store weight prior to search, lb.
	SCALEI(K),K=1,3	Factors to be used to scale store moments of inertia about x, y, and z axes, lb.-in.^{2}
	SCALER(K),K=1,3	Factors to be used to scale store center-of-gravity x, y, and z offsets relative to nominal store/pylon attachment point, in.
	SCALEF(K),K=1,6	Factors to be used to scale flexibility-matrix diagonal elements for translations in x, y, and z axes at nominal store/pylon attachment point, in./lb. or rad./in.-lb.

A suggested approach for selecting the above factors is to set each of them equal to the difference between the maximum and minimum values (of the corresponding store parameter) to be considered during the search. This will result in the store-search region being scaled to fit within a unit multi-dimensional cube, which is desirable for efficient searches.

A parameter may be held fixed during a search by setting the corresponding scale factor equal to zero.

Format = (E15.5/3E15.5/3E15.5/6F10.3). Number of cards is 4.

Data are entered by subroutine READY.

Item 8J ISTEP

Search step number at which present submittal begins.

For starting a new search, let ISTEP = 1.

For a restart from a previous search, set ISTEP equal to the cycle number obtained from the end of the printed output for the previous series of search steps.

If ISTEP > 1, a separate restart data file, obtained via unit 48 in the previous submittal, must be provided as input to this submittal via unit 47. See Section 4.

KCONST = 0

Store pitch and yaw inertias are slaved together and considered as a single search variable.

Using this option requires that each pair of initial values and scale factors for these two quantities be identical.

= 1

Store pitch and yaw inertias are considered as independent search variables.

Format = (2I5,5X). Number of cards is 1.

Data are entered by subroutine READY.

Item 8K VNEW

For a restart submittal, set VNEW to flutter speed obtained from next-to-last search step in previous submittal in which a reduction in flutter speed was achieved, knots eas.

For starting a new search, set VNEW to any large value that is greater than VS below.

VS

Factor to be used to scale flutter speed, knots eas.

Suggest a value approximately equal to the largest anticipated flutter speed for any store configuration.

Format = (E10.3,10X,E10.3). Number of cards is 1.

Data are entered by subroutine READY.

Item 8L Blank card

Item 8M | ITOC1 = 0 | Boundaries of store-parameter/pylon-flexibility space to be searched are defined by discrete points. This option is applicable only to types of search spaces defined in Item 8U.

= 1 | Search-space boundaries are defined by linear constraint equations. See Eq. (3-1), page 3-1, Reference 4.

Format = (I5). Number of cards is 1.

Data are entered by subroutine INCONS.

Item 8N | Logic Item - No Data

If ITOC1 = 0, go to Item 8T. If ITOC1 = 1, continue with Items 8P - 8S below.

Item 8P | MSTAR | Number of constraint planes (linear constraint equations) used to define search-space boundaries. Maximum number is 50.

Format = (I5). Number of cards is 1.

Data are entered by subroutine INCONS.

Item 8Q | Logic Item - No Data

Repeat Items 8R - 8S for I = 1,MSTAR.[1]

Item 8R | G(J,I),J=1,NPARM | Each column, I, consists of components of a unit normal vector pointing outward from the scaled search space to the Ith constraint plane. In general, rows, J, should correspond in order and total number (NPARM) to the search variables for which non-zero scale factors are entered in Item 8I; however, if KCONST = 0, only one element should be entered for each pair of pitch and yaw inertias to be searched. The order in which columns, I, are associated with constraint planes is arbitrary. Maximum total number of search variables, NPARM, is 35.

Format = (3(E15.5,5X)). Number of cards is (NPARM-1)/3 + 1.

Data are entered by subroutine INCONS.

---

[1] Additional discussion of procedures for defining constraint planes, and, more specifically, Items 8R and 8S, is contained in Subsection 5.3 and Appendix C.

Item 8S B(I) Scaled distance from origin to Ith constraint plane in direction of unit normal vector. Constitutes Ith element in b vector in Eq. (3-1), page 3-1, Reference 4.

Format = (E15.5). Number of cards is 1.

Data are entered by subroutine INCONS.

Item 8T Logic Item - No Data

If ITOC1 = 1, go to Item 9. If ITOC1 = 0 repeat Items 8U - 8GG for each store station. Number of store stations is defined by the last value of IDSTR in Item 8B.

Item 8U ITOC = 1 Search variables for this store station consist of store mass, store pitch or pitch/yaw inertia, and up to six pylon-flexibility parameters. This option is intended primarily for store stations with single-store ejector racks.

= 2 Search variables for this store station consist of store mass, store pitch or pitch/yaw inertia, store center-of-gravity x offset, and up to six pylon-flexibility parameters. This option is intended primarily for store stations with multiple-store ejector racks.

= 3 Search variables for this store station consist exclusively of up to six pylon-flexibility parameters.

Format = (I5). Number of cards is 1.

Data are entered by subroutine INCONS.

Item 8V Logic Item - No Data

If ITOC = 1 and at least one of the first four factors in Item 8I is nonzero for the store station currently being considered, continue with Items 8W - 8Z below. If ITOC = 1 and all of these factors are zero, continue with Items 8EE - 8GG.

If ITOC = 2 and at least one of the first seven factors in Item 8I is nonzero for the store station currently being considered, continue with Items 8AA - 8GG. If ITOC = 2 and all of these factors are zero, continue with Items 8EE - 8GG.

If ITOC = 3, continue with Items 8EE - 8GG.

Item 8W	NCORN	Number of vertices defining polygon for two-dimensional store-parameter search space. Maximum number is 10.

Format = (I5). Number of cards is 1.

Data are entered by subroutine INCONS.

Item 8X — Logic Item - No Data

Repeat Item 8Y below for each of the NCORN vertices. The vertices are defined sequentially in a clockwise direction assuming store mass is the abscissa and store inertia is the ordinate of the two-dimensional store-parameter space.

Item 8Y	CORNM(J)	Store mass at Jth vertex, lb.
	CORNI(J)	Store pitch moment of inertia at Jth vertex, $lb.-in.^2$

Format = (2(E15.5,5X)). Number of cards is 1.

Data are entered by subroutine INCONS.

Item 8Z — Logic Item - No Data

Continue with items 8EE - 8GG.

Item 8AA	NCONST	Number of constraint planes defining three-dimensional store-parameter search space. Maximum number determined by requirement that total number of constraint planes be less than or equal to 50 considering all store stations and both store-parameter and pylon-flexibility search variables.

Format = (I5). Number of cards is 1.

Data are entered by subroutine INCONS.

Item 8BB — Logic Item - No Data

Repeat Items 8CC - 8DD below for each of the NCONST constraint planes.

Item 8CC Logic Item - No Data

Repeat Item 8DD below for three points on each constraint plane. The points should be entered sequentially in a clockwise direction looking in toward the region to be searched, and assuming that store mass, store pitch inertia, and store center-of-gravity x offset (in that order) constitute the x, y, and z axes, respectively, of a right-handed coordinate system.

Item 8DD CORNM(K) Store mass at Kth point on constraint surface, lb.

CORNI(K) Store pitch moment of inertia at Kth point on constraint surface, lb.-in.^{2}

CORNS(K) Store center-of-gravity x offset at Kth point on constraint surface, in. Positive for store center-of-gravity location forward of pylon attachment point.

Format = (3(E15.5,5X)). Number of cards is 1.

Data entered by subroutine INCONS.

Item 8EE NSTAR Number of constraint planes for pylon-flexibility search variables. Only an upper and a lower limit for each pylon-flexibility variable may be specified. Maximum number is 12.

Format = (I5). Number of cards is 1.

Data are entered by subroutine INCONS.

Item 8FF Logic Item - No Data

Repeat Item 8GG below for each of the NSTAR pylon-flexibility constraint planes. If NSTAR = 0, skip Item 8GG.

Item 8GG IDOF Pylon-flexibility dynamic degree of freedom to be constrained. Enter with either a positive or negative sign to denote whether associated constraint value (next parameter) is an upper or lower flexibility limit.

CLIMIT Maximum or minimum flexibility for degree of freedom specified in previous parameter, in./lb. or rad./in.-lb.

Format = (I5,E15.5). Number of cards is 1.

Data are entered by subroutine INCONS.

Items 9,10 FASTOP logic/data items not used in ESP.

Items 11 FASTOP data item not used in ESP. (Superseded by separate file containing dynamic mass matrix. See Subsection 5.1)

Items 12-15 FASTOP logic/data items not used in ESP.

Item 16 Logic Item - No Data

If a free-free wing is being analyzed (KLUE(37) = 37), continue below with Items 16A - 17. Otherwise (KLUE(37) = 0), omit these items.

Item 16A	NPGDOF	Number of plug dynamic degrees of freedom. Should correspond to the number of modes in the rigid-body displacement matrix, and the number of rows and columns in the plug mass matrix, both of which are entered in separate files. See Subsection 5.1. Maximum value is 3.

Format = (I5). Number of cards is 1.

Data are entered by subroutine FFMASS.

Item 17 FASTOP data item not used in ESP. (Superseded by separate file containing plug mass matrix. See Subsection 5.1.)

Items 18, 19 FASTOP logic/data items not used in ESP.

Item 20	NROOTS	Number of normal modes of vibration to be computed. Maximum number is 40 if KLUE(38) = 0, and (40 - NPGDOF) if KLUE(38) = 38.
	NDOFFF	Number of displacements per mode which are to be saved for use in the flutter-analysis module. Note that only out-of-plane displacements are used in AFAM except when the elastic-axis option is specified. Maximum number is NDYDOF.
	NZERO	Number of additional displacements per mode which are to be set to zero for use in the flutter-analysis module. See Item 21 below. Maximum number is (220 - NDOFFF).

Format = (3I5). Number of cards is 1.

Data are entered by subroutine EIGEN.

[illegible] 0A Logic Item - No Data

If rigid-body modes are not to be included in the output from the vibration-analysis module to the flutter-analysis module (KLUF(38) = 0), omit the following item.

[illegible] 20B FREQ(N),N=1,NPGDOF Zero-airspeed frequencies to be assigned to rigid-body modes in flutter analysis, Hz. To avoid numerical problems, values above 0.005 Hz. are suggested; values less than 0.002 Hz. will be reset to 0.002 Hz. within the program. See Section 3 for additional comments on the use of this input-data item.

Format = (3E10.3). Number of cards is 1.

Data are entered by subroutine VIBIFO.

[illegible] Logic Item - No Data

The two variables in the following item permit the user to reorder and/or eliminate the modal displacements calculated in the vibration-analysis module in preparation for their use in the flutter-analysis module. Further, additional modal displacements may be set to zero. The requirements for ordering modal displacements for the flutter-analysis module are given in Reference 5, Volume II, pages 207 and 208.

The two items should be entered in pairs for I=1,NDOFFF.

[illegible] IDFV(I) Degree-of-freedom number used in the vibration analysis which corresponds to the flutter-analysis degree-of-freedom number entered for the following variable. Maximum value is NDYDOF.

IDFF(I) Degree-of-freedom number to be used in the flutter analysis. Must be specified in ascending order. Omitting a degree-of-freedom number will result in the modal displacements for that degree of freedom being set to zero. Maximum value is (NDOFFF + NZERO).

Format = (5(2I4)). Number of cards is ((NDOFFF-1)/5 + 1).

Data are entered by subroutine VIBIFO.

[illegible] Identical to FASTOP.

5.2.3 - Data Entered Via Flutter-Analysis Module

(See also Reference 1, Volume II, pages 217-274, or Reference 5, Volume II, pages 245-302)

Items 1-3	Identical to FASTOP.	
Item 4	LC(1) = -1	Store search or p-k flutter analysis.
	= 0	Pressure calculations only.[1]
	= 1	k flutter analysis
	= 2	Divergence analysis.[1]
	LC(2)	Number of vibration modes, including rigid-body modes, to be used in flutter analysis. Maximum number is 40.
	LC(3)	Number of lifting surfaces. For the doublet-lattice method, which is the only aerodynamic theory that is operational in ESP, the maximum number is 30.
	LC(4)	Number of reduced velocities for which aerodynamic pressures and/or generalized forces are to be computed or interpolated depending on the value of LC(13). If LC(1) = 0 or 1, LC(4) must be less than or equal to 30. If LC(1) = 2, let LC(4) = 1. If LC(1) = -1, LC(4) is the number of reference reduced velocities (see Item 19A), and must be less than or equal to 15.
	LC(5)	Number of air densities for which the flutter or divergence analyses will be run.[2] Maximum number is 10. If LC(1) = 0, let LC(5) = 0. If KLUE(7) = 7, let LC(5) = 1.
	LC(6) = 0	Dummy variable in ESP.
	LC(7) = 1	List calculated pressures.[1]
	= 0	No display.
	LC(8) = 1	List lift and moment coefficients.[1]
	= 0	No display.

---

[1] Not checked in ESP

[2] Checked for LC(5) > 1.

Item 4 (cont.)	LC(9) = 1	Frequency-independent additions to the aerodynamic matrix $\overline{Q}$ are to be read as data.[1,2]
	= 0	No such additions are to be made.
	LC(10) = 1	List the full set of interpolated generalized[1] forces when using k flutter method.
	= 0	No display.
	LC(11)	Index in flutter-analysis module of modal frequency to be used as a normalization factor in the flutter determinant. Suggest index of first flexible mode.
	LC(12) = 1	Flutter determinant is formulated as the product of the inverse of the generalized stiffness matrix and the sum of the generalized-mass and aerodynamic-force matrices.[1]
	= 0	Determinant is formulated as the product of the inverse of the sum of the generalized-mass and aerodynamic matrices, and stiffness matrix.
		If rigid-body or other very-low-frequency modes are present in the analysis, let LC(12) = 0.
	LC(13) = 1	Generalized-aerodynamic-force interpolation is used.
	= 0	Generalized aerodynamic forces are computed[1] directly at each reduced frequency.
		If LC(1) = -1, let LC(13) = 1. If LC(1) = 0 or 2, let LC(13) = 0. If LC(1) = 1, let LC(13) = 0 or 1.
	LC(14) = 1	CalComp plots of the flutter solution are to be produced.
	= 0	No plots.
	LC(15) = 1	Velocity scale in the flutter-solution plots is in terms of true airspeed.
	= 0	Scale is equivalent airspeed.

[illegible] Assumed [illegible].

[illegible] Volume I, page 84.

6 - OUTPUT DESCRIPTION

Since the current version of ESP was developed as a pilot code to investigate and demonstrate the store-search procedure in an expedient manner, the output from the new code is not always as well structured and/or annotated as would be desirable in a production program. To partially compensate for this limitation, and also to provide an introduction to the output from ESP, portions of typical ESP output listings are presented and discussed in this section. Output related to NASTRAN dynamics-model input matrices is discussed in Appendix A.

6.1 - VIBRATION-ANALYSIS MODULE

Other than the optional listing of the input flexibility matrix, the first group of output from an ESP search run consists of store-parameter data as illustrated in Figure 6-1. NUMBER, at the top of the figure, identifies the store-station number; this value is the same as IDSTR that was input as Item 8B. The next line, DYNAMIC DOF, identifies the dynamic-degree-of-freedom numbers at the nominal store/pylon attachment point; these values are the same as the IDYDOF's that were input as Item 8H. The store-parameter values, which constitute the bulk of the output in Figure 6-1, are listed in the same order and in the same units as the input-data quantities described in Items 8C - 8F. PFX, PFY, and PFZ, and PFXX, PFYY, and PFZZ denote pylon-flexibility values corresponding to translations in the x, y, and z directions and rotations about the x, y, and z axes. For the first analysis cycle in each job submission, the INITIAL and CURRENT values are identical, and the DELTA is zero.

Immediately after the store-parameter data, but only for the first analysis cycle in each job submission, is a listing of the coefficient matrix, G, and the vector, b, in Eq. (3-1), page 3-1, Reference 4. When ITOCI = 1 in Item 8Q of the input data, this listing, illustrated in Figure 6-2, is identical to the input data specified in Items 8R and 8S (except that, for input, the transpose of G is specified by rows, whereas, for output, G itself is listed by rows). When ITOCI = 0, G and b are calculated by the program based on store-parameter data values entered via Items 8U - 8GG.

```
80.     [illegible]                                                            FI,ACAP          2R
        2     [illegible]               1                                     NDELT,ETC.       3R
0.0     -33.0     0.0       0.0                                                XO,ETC.          4R
171.64  341.2     337.5     389.96    33.0      318.0                          X1,ETC.          5R
0.0     0.0         9  6                                                       Z1,ETC.          6R
0.0     0.2       0.4       0.6       0.8       1.0                            TH               7R
0.0     0.125     0.25      0.375     0.50      0.625                          TAU              8R
0.75    0.875     1.00                                                         TAU              8R
0.0     -13.0     0.0       0.0                                                XO,ETC.          4R
515.1   607.3     591.0     630.8     13.0      122.0                          X1,ETC.          5R
0.0     0.0         6  5                                                       Z1,ETC.          6R
0.0     0.25      0.5       0.75      1.0                                      TH               7R
0.0     0.2       0.4       0.6       0.8       1.0                            TAU              8R
    1     0     0     0     0     0                                            NSTRIP,ETC.     14R
   0  0                                                                        LIM             15R
    F    40     0                                                              KSURF,ETC.      16R
    2     1     0     0                                                        NLINES,ETC.     17R
    4 265.0   0.0       265.0     102.14                                       NGP,ETC.        18R
30.5    50.0      71.0      102.14                                             YGP             19R
    7 265.0   102.14    354.4     318.0                                        NGP,ETC.        18R
115.0   141.0     170.0     205.0     250.0     281.1     307.0                                19R
10.0                                                                           DIST            21R
    F    20     0                                                              KSURF,ETC.      16R
    1     1     0     0                                                        NLINES,ETC.     17R
    3 541.7   0.0       607.5     122.0                                        NGP,ETC.        18R
0.0     60.0      117.5                                                        YGP             19R
10.0                                                                           DIST            21R
    1                                                                          KLUGLB          33R
F000                                                                           F000             2
        SEARCH OF A-6                                                                           3
                                                                               BLANK CARD       4
2222.2                                                                         VDES             6
      8                                                                        NFIX             7
                                                                               BLANK CARD       8
```

Figure 5-2 - Illustrative Primary Input-Data File (4 of 4)

```
   3
  14  28   0
0.005     0.005     0.005                                                  FREQ            20B
                                                                           NPGDOF          16A
                                                                           NROOTS,ETC.     20
  95   1  97   2  89   3  91   4  83   5                                   IDFV,IDFF       21
  84   6  69   7  70   8  65   9  66  10                                   IDFV,IDFF       21
  51  11  53  12  47  13  48  14  35  15                                   IDFV,IDFF       21
  36  16  22  17  23  18  14  19  15  20                                   IDFV,IDFF       21
   3  21   5  22 110  23 111  24 107  25                                   IDFV,IDFF       21
 108  26 104  27 105  28                                                   IDFV,IDFF       21
FA00                                                                       FA00             1
 DOUBLET-LATTICE                                                                            2
   0                                                                       KLUEF            3
  -1    16     2    15     1     0     0     0     0     0                 LC  1-10         4
   3     0     1     1     1     1     1     0     0     0                 LC 11-20         4
   1     1     0     0     0     0     0     0     0     0                 LC 21-30         4
   0     0     0     0     0     0     1     1                             LC 31-38         4
   3                                                                       IN               5
   2     3     4     5     6     7     8     9    10    11                 IFLMD           14
  12    13    14    15    16    17                                         IFLMD           14
40.       0.90                                                             BR,FMACH        15
   8 80.0      120.0                                                       NV,V1,DV        19
  15                                                                       NRVBO           19A
0.1       0.2       0.4       0.8       1.6       3.2       6.4       RVBO 20
12.5      25.0      50.0      100.0     250.0     700.0     2000.0    RVBO 20
1.E+05                                                                RVBO 20
0.02                                                                       GDD             27
   1     2                                                                 NRBTR,NRBTOT    29A
0.10      -0.40     1000.     50.0                                         GMAX,ETC.       30
 ILLUSTRATIVE CALCOMP PLOT OF FLUTTER-ANALYSIS RESULTS                                     32
                    F-K METHOD                                                             32
   1 0.10      40.0      600.0     -0.30                                   LSD,ETC.        33
0.1       10.0      100.0                                                  DSCALE,ETC.     34
0.7393                                                                     RHOR            35
0.0025    450.0                                                            QDW,VQDW        51B
```

Figure 5-2 - Illustrative Primary Input-Data File (3 of 4)

[illegible]	[illegible]	[illegible]	G(J,1)	8R
[illegible]	[illegible]	0.0	G(J,1)	8R
[illegible]			B(1)	8S
-.2[illegible]	.25676	0.0	G(J,2)	8R
0.0	0.0	0.0	G(J,2)	8R
.2647			B(2)	8S
-1.0	0.0	0.0	G(J,3)	8R
0.0	0.0	0.0	G(J,3)	8R
-.33135			B(3)	8S
1.0	0.0	0.0	G(J,4)	8R
0.0	0.0	0.0	G(J,4)	8R
.94595			B(4)	8S
0.0	0.0	1.0	G(J,5)	8R
0.0	0.0	0.0	G(J,5)	8R
1.5			B(5)	8S
0.0	0.0	-1.0	G(J,6)	8R
0.0	0.0	0.0	G(J,6)	8R
-0.5			B(6)	8S
0.0	0.0	0.0	G(J,7)	8R
.2588	-.96590	0.0	G(J,7)	8R
-.0850			B(7)	8S
0.0	0.0	0.0	G(J,8)	8R
.7420	-.6704	0.0	G(J,8)	8R
.1499			B(8)	8S
0.0	0.0	0.0	G(J,9)	8R
1.0	0.0	0.0	G(J,9)	8R
1.0			B(9)	8S
0.0	0.0	0.0	G(J,10)	8R
-.7138	.7003	0.0	G(J,10)	8R
-.0135			B(10)	8S
0.0	0.0	0.0	G(J,11)	8R
-.2865	0.0	.9581	G(J,11)	8R
.2784			B(11)	8S
0.0	0.0	0.0	G(J,12)	8R
.8503	0.0	.5264	G(J,12)	8R
.8439			B(12)	8S
0.0	0.0	0.0	G(J,13)	8R
.1474	0.0	-.9891	G(J,13)	8R
.4776			B(13)	8S

Figure 5-2 - Illustrative Primary Input-Data File (2 of 4)

```
                                                                                     FOP,LINESI      1
[illegible] ANALYSIS - INBD & OUTBD UPPER SPACE SEARCH W PYLON FLEX                  2
[illegible] SYMM, NO WING FUEL, LUMPED TAIL, 2% STR DAMPING, FREEZE IYY OUTBD        2
    0                                                                                KTITLE          3
    0    0    3    4    0    0    7    0    0    0                                  KLUE  1-10      6
    0    0    0    0    0    0   27    0    0    0                                  KLUE 21-30      6
    0    0    0   34    0    0   37  -38                                            KLUE 31-38      6
VA00                                                                                 VA00            1
FLEX., MASS AND TRANSF. MATRICES ARE SEPARATE CARD-IMAGE FILES                                       2
    0    0    0    0    0    0   -7                                                 KLUEV 1-8       3
  206     0      0      0                                                            NDYDOF,ETC      3A
    1                                                                                IDSTR - OUTBD   8B
2845.0                                                                               STRWI           8C
1.00             6370000.          6370000.                                          STRII           8D
+20.637          0.0               13.0                                              STRRI           8E
0.0         0.0         0.0        0.0         0.0         0.0                       STRSI           8F
    0     0     0     0     0     0                                                  ISTDOF          8G
  173   174   175   176   177   178                                                  IDYDOF          8H
3700.                                                                                SCALEW          8I
0.0              0.0               0.0                                               SCALEI          8I
41.              0.0               0.0                                               SCALER          8I
0.0         0.0         0.0        0.0         2.8E-08     0.0                       SCALEF          8I
    2                                                                                IDSTR - INBD    8B
3500.                                                                                STRWI           8C
1.0              9500000.          9500000.                                          STRII           8D
-6.819           0.0               13.0                                              STRRI           8E
0.0         0.0         0.0        0.0         0.0         0.0                       STRSI           8F
    0     0     0     0     0     0                                                  ISTDOF          8G
  190   191   192   193   194   195                                                  IDYDOF          8H
3500.                                                                                SCALEW          8I
0.0              9500000.          9500000.                                          SCALEI          8I
39.              0.0               0.0                                               SCALER          8I
0.0         0.0         0.0        0.0         0.0         0.0                       SCALEF          8I
                                                                                     BLANK CARD
    1     0                                                                          ISTEP,KCONST    8J
10000.                1000.                                                          VNEW,VS         8K
                                                                                     BLANK CARD      8L
    1                                                                                ITOC1           8M
   13                                                                                MSTAR           8P
```

Figure 5-2 - Illustrative Primary Input-Data File (1 of 4)

5.3 - LISTING OF SAMPLE PRIMARY INPUT-DATA FILE

An input-data file illustrating the use of many of the data items described above is shown in Figure 5-2. The case shown is for a maximum of eight store-parameter search steps in a six-dimensional space in which store weight, longitudinal center of gravity, and pylon flexibility are allowed to vary at one store station, and store weight, longitudinal center of gravity, and slaved pitch/yaw inertia are to be varied at a second station. The constraint planes which constitute the search-space boundaries are defined in terms of unit normal vectors and distances from the search-space origin.

Note that each constraint-plane unit normal vector (Item 8R) has at most two components, and that both components, when two are present, pertain to parameters at the same store station. Two significant implications of these characteristics of the constraint-plane data are as follows. First, the permissible range of store-parameter variations at one station is fully independent of the values at the other station. Second, each constraint plane will appear as a line in at least one two-dimensional space: For a unit normal vector having two nonzero components, this two-dimensional space is the one containing the two nonzero components. When the unit normal has only one nonzero component, the constraint plane becomes a line in any two-dimensional space for which one of the variables corresponds to the nonzero component; by definition, the axis corresponding to the single nonzero unit-normal component will be normal to this line.

As is discussed in Appendix C, the specification of constraint planes for three-dimensional searches in terms of two-component unit normals not only greatly facilitates the definition of the search boundaries, but also has the potential for producing a constrained search space with little open volume near the periphery. Therefore, this approach is recommended whenever search in a three-parameter space at each store station is deemed useful.

for the next analysis cycle. However, since it is in the search module that ESP achieves its primary technical distinction from FASTOP, the name of this module has been changed herein from that of its FASTOP predecessor.

Nevertheless, since some of the input associated with the FASTOP flutter-optimization module is still present in the current pilot-code version of ESP, the practice of relating ESP input data to corresponding FASTOP input-data item numbers will be retained in this module as well.

Item 1 Logic Item - No Data

If a search is to be performed to determine store-mass and/or pylon-flexibility parameters corresponding to a minimum flutter speed (KLUE(7) = 7), continue with Items 2 - 8 below. If only an analysis is to be performed (KLUE(7) = 0), omit these items.

Items 2,3 Identical to FASTOP

Item 4 Blank card in ESP.

Item 5 FASTOP logic item not used in ESP.

Item 6 VDES Velocity greater than maximum anticipated flutter speed during search, knots equivalent airspeed.

Format = (F10.3,20X). Number of cards is 1.

Data are entered by subroutine AFOM.

Item 7 NFIX Maximum number of search steps to be taken in this job submission. The program will stop in less than NFIX steps if a minimum flutter speed is located.

Format = (5X,I5). Number of cards is 1.

Data are entered by subroutine AFOM.

Item 8 Blank card in ESP.

Item 29A (cont.) Format = (2I5). Number of cards is 1.

Data are entered by subroutine FLINFO.

Items 30-51 Identical to FASTOP.

Item 51A Logic Item - No Data

If modes having low ratios of on-diagonal generalized force to corresponding generalized mass are to be automatically excluded from a p-k flutter analysis (LC(1) = -1 and LC(38) = 1), enter data for the following item. Otherwise (LC(1) ≠ -1 or LC(38) = 0), omit this item.

Caution is advised when using this mode-elimination option in conjunction with store-parameter searches. Derivative calculations, and resulting search steps, can be much more sensitive than the flutter characteristics themselves to the system-idealization changes resulting from mode eliminations.

Item 51[illegible]	ODW	Ratio of modulus of on-diagonal generalized force to value of corresponding generalized mass below which a mode will be excluded from p-k flutter analysis.
	VQDW	Nominal velocity at which generalized forces used in above ratio are to be computed, knots tas. (Generalized forces are actually computed and used at 0.75*VQDW, VQDW, and 1.25*VQDW.)

Format = (2E10.3). Number of cards is 1.

Data are entered by subroutine FLINFO.

[illegible] Identical to FASTOP.

[illegible]-[illegible]K Identical to FASTOP.

[illegible]-[illegible]M FASTOP logic/data items not used in ESP.

[illegible]-[illegible]8F FASTOP logic/data items not used in ESP.

Data Entered Via Search Module

(See also Reference [illegible], Volume II, pages 275-279, or Reference 5, Volume [illegible], pages [illegible].)

[illegible] store-parameter search module in ESP is similar to the flutter-[illegible] module in FASTOP [illegible] the extent that both modules determine [illegible] parameters that are to be implemented to define the data

Item 20	RVBO(I),I=1,NRVBO	Reference reduced velocities.

The values should be input in ascending order, and should span the entire range of reduced velocities required for the flutter analysis.

For the k method, this implies that RVBO(1) ≤ VBO(1) (see Item 17), and that RVBO(NRVBO) ≥ VBO(LC(4)).

For the p-k method, the following approximation is suggested:

- RVBO(1) ≤ 1.69*12*VMIN/(BR*6.28*FMAX)
- RVBO(NRVBO) ≥ 1.69*12*VMAX/(BR*6.28*FMIN)

where

- VMIN = V1, knots (see Item 19)
- VMAX = V1 + (NV-1)*DV, knots
- FMAX and FMIN are the maximum and minimum zero-airspeed frequencies in Hz.
- BR is the reference semichord, in. (see Item 15).

If FMIN ≤ 0.01, let RVBO(NRVBO) = 1.0E+05 and RVBO(NRVBO-1) = 2000.

Format = (7E10.0). Number of cards is ((NRVBO-1)/7 + 1).

Data are entered by subroutine FLINFO.

Item 21-25 Identical to FASTOP.[1]

Item 26 Logic Item - No Data

If no structural damping is added to the stiffness matrix (LC(16) = 0), omit the following three items, and go to Item 29A.

If different structural damping values are added to the complex stiffness matrix for each mode (LC(16) = -1), omit Item 27, and go to Item 28.

If the same value of damping is added for all modes (LC(16) = 1), enter data for Item 27 and omit Items 28 and 29.

Items 27-29 Identical to FASTOP.

Item 29A	NRBTR	Number of rigid-body translation modes included in IFLMD(I), Item 14.
	NRBTOT	Total number of rigid-body modes included in IFLMD(I).

---

[1] Not applicable to store-parameter search runs.

Item 16 Logic Item - No Data

For divergence analysis (LC(1) = 2), omit Items 17 - 34, and go to Item 35.

For steady-state pressure calculations only (LC(1) = 0 and LC(33) = 1), omit Items 17 - 55, and go to Item 56.

For p-k flutter analysis (LC(1) = -1), omit the following two items, and go to Item 19.

For k flutter analysis (LC(1) = 1), or for oscillatory pressure calculations (LC(1) = 0 and LC(33) = 0), continue with Item 17 below.

Item 17 [illegible](I),I=1,LC(4) Reduced velocities to be used in k flutter analysis or in oscillatory pressure calculations.

Format = (7E10.0). Number of cards is ((LC(4)-1)/7 + 1).

Data are entered by subroutine FLINFO.

[illegible] Logic Item - No Data

Based on Item 16, this item is reached only for k flutter analysis (LC(1) = 1) or for oscillatory pressure calculations (LC(1) = 0 and LC(33) = 0).

For k flutter analysis with generalized-aerodynamic-force interpolation (LC(1) = 1 and LC(13) = 1), omit the following item, and go to Item 19A.

For k flutter analysis with directly computed generalized forces (LC(1) = 1 and LC(13) = 0), omit Items 19 - 20, and go to Item 21.

For oscillatory pressure calculations (LC(1) = 0 and LC(33) = 0), omit Items 19 - 55, and go to Item 56.

[illegible] [illegible] FASTOP.

[illegible] Number of reference reduced velocities, i.e., number of reduced velocities and corresponding directly computed generalized-aerodynamic-force matrices that will be used as a basis for generalized-force interpolation. Maximum value is 15.

Format = [illegible]. Number of cards is 1.

Data are entered by subroutine FLINFO.

Item 4 (cont.)	= 0	No display.
	LC(38) = 1	User will input a ratio of on-diagonal generalized force to corresponding generalized mass which will be used for automatic exclusion of vibration modes from a p-k flutter analysis.[2]
	= 0	All modes initially selected by user will be used in the flutter analysis.
		If LC(1) $\neq$ -1, let LC(38) = 0.

Format = (10I5). Number of cards is 4.

Data are entered by subroutine AFAM.

Item 5	IN = 1	Modal vibration data are input on cards.[1,3]
	= 2	Not used in ESP.
	= 3	Modal data are obtained from vibration-analysis module.

Format = (I5). Number of cards is 1.

Data are entered by subroutine POOL.

Items 6-12 Identical to FASTOP.[3]

Item [illegible] FASTOP data item not used in ESP.

Item [illegible]4	IFLMD(I),I=1,LC(2)	Indices of modes from vibration-analysis module to be used in the flutter analysis. I is the mode index in the flutter-analysis module that corresponds to IFLMD in the vibration-analysis module.

Format = (10I5). Number of cards is ((LC(2)-1)/10 + 1).

Data are entered by subroutine POOL.

Item [illegible] Identical to FASTOP.

Option not checked in ESP.

See cautionary comment in footnote to item 51A.

Not applicable to store-parameter search runs.

Item 4 (cont.)	LC(29) = 1	Display physical vectors corresponding to the displayed modal eigenvectors.[1]
	= 0	No display.
	LC(30) = 1	Display flutter determinant in k flutter analysis (see LC(12)).[1]
	= 0	No display.
		If LC(1) = -1 or 0, let LC(30) = 0.
	LC(31) = 1	User will input changes to the generalized masses and the modal frequencies.[1]
	= 0	No changes.
	LC(32) = 1	User will input revisions to the generalized stiffness matrix.[1]
	= 0	No revisions.
	LC(33) = 1	Steady-state analysis.[1]
	= 0	Oscillatory analysis.
		If LC(1) = 2, let LC(33) = 1.
	LC(34) = 1	User will input factors to scale the computed aerodynamic forces.[1]
	= 0	No factors.
	LC(35) = 0	Fixed value in ESP. LC(35) = 1 is associated with Mach-box aerodynamics, which is not operational in ESP.
	LC(36) = 1	Compute eigenvectors and the aerodynamic force gradients required for flutter redesign.
	= 0	Do not compute.
		If LC(1) ≠ -1, let LC(36) = 0.
		If KLUE(7) = 7, eigenvectors and gradients are always computed.
	LC(37) = 1	For doublet-lattice program, display geometric data associated with basic doublet elements.

---

[1] Option not checked in ESP.

Item 4 (cont.)	LC(22) = 0	Compute AIC arrays[3] as part of this job submission and save as output data file.
	= 1	AIC arrays exist as an input data file, and do not need to be recomputed.
	LC(23) = 1	Display modal input data.[1]
	= 0	No display.
	LC(24) = 1	Display interpolated modal data.[1]
	= 0	No display.
	LC(25)	Number of user-specified mode-elimination cycles requested for the flutter analysis. (Distinct from automatic mode elimination specified via LC(38).) Maximum number is 25.[2] If KLUE(7) = 7, let LC(25) = 0.
	LC(26)	Number of stiffness-variation cycles requested for the flutter analysis. Maximum number is 20.[2] If KLUE(7) = 7, let LC(26) = 0.
	LC(27)	Index of the vibration mode whose stiffness is to be varied in the flutter analysis. If LC(26) = 0, let LC(27) = 0.
	LC(28) = 1	Display eigenvectors.[1] If LC(1) = -1, the eigenvectors for the critical flutter root in a user-specified velocity interval is displayed. If LC(1) = 1, the eigenvectors for all roots between user-specified reduced velocities and real frequencies are displayed.
	= 0	No display.
		If LC(1) = 0 or 2, let LC(28) = 0.
		If LC(1) = -1 and LC(36) = 1, the eigenvector corresponding to the critical flutter root and flutter speed is always displayed.

Option not checked in ESP.

ESP not checked for value other than zero.

Actual quantities saved are not AIC's, but intermediate results of equation-solution procedure (see Reference 7, pages 34-35).

Item 4 (cont.)	LC(16) = 0	No structural damping is added to the complex generalized-stiffness matrix.[2]
	= -1	Different damping values are added to the generalized-stiffness matrix for each mode.
	= 1	The same value of damping is added for all modes.
	LC(17) = 1	Display the number of iterations required to obtain each root in the p-k flutter analysis.
	= 0	No display.
		If LC(1) ≠ -1, let LC(17) = 0.
	LC(18) = 1	For the third and higher velocities in the p-k flutter analysis, the initial estimate of each root is obtained by extrapolating from the root values at the previous two velocities.[1]
	= 0	The value of the root at the previous velocity is used as the root estimate.
		If LC(1) ≠ -1, let LC(18) = 0.
	LC(19) = 1	Order the roots after[1] solution by the p-k flutter analysis.
	= 0	No ordering.
		If LC(1) ≠ -1, let LC(19) = 0.
	LC(20) = 1	Display the root iterations in the p-k flutter analysis (LC(1) = -1), or display intermediate results[1] of the k flutter analysis (LC(1) = 1).
	= 0	No display.
	LC(21) = 1	Fixed value in ESP. Denotes use of subsonic doublet-lattice aerodynamics. Supersonic Mach-box and subsonic assumed-pressure-function methods are not operational in ESP.

---

[1] Option not checked in ESP.

[2] When performing store-parameter searches, this option is not recommended. Rather, the introduction of realistic structural-damping values is suggested to avoid numerical problems that might be encountered when some modes have very low levels of aerodynamic damping.

NUMBER= 1

DYNAMIC DOF = 173 174 175 176 177 178

	INITIAL VALUE	CURRENT VALUE	DELTA VALUE
WEIGHT..	.28450E+04	.30066E+04	.16156E+03
IXX ..	.10000E+01	.10000E+01	0.
IYY ..	.63700E+07	.63700E+07	0.
IZZ ..	.63700E+07	.63700E+07	0.
RX ..	.20837E+02	.21376E+02	.53909E+00
RY ..	0.	0.	0.
RZ ..	.13000E+02	.13000E+02	0.
PFX ..	.11162E-04	.11162E-04	0.
PFY ..	.39162E-04	.39162E-04	0.
PFZ ..	.53553E-04	.53553E-04	0.
PFXX ..	.13290E-06	.13290E-06	0.
PFYY ..	.28086E-07	.30183E-07	.20970E-08
PFZZ ..	.61730E-07	.61730E-07	0.

NUMBER= 2

DYNAMIC DOF = 190 191 192 193 194 195

	INITIAL VALUE	CURRENT VALUE	DELTA VALUE
WEIGHT..	.35000E+04	.35000E+04	0.
IXX ..	.10000E+01	.10000E+01	0.
IYY ..	.95000E+07	.95000E+07	0.
IZZ ..	.95000E+07	.95000E+07	0.
RX ..	-.68190E+01	-.64486E+01	.37037E+00
RY ..	0.	0.	0.
RZ ..	.13000E+02	.13000E+02	0.
PFX ..	.47387E-05	.47387E-05	0.
PFY ..	.39426E-04	.39426E-04	0.
PFZ ..	.17257E-04	.17257E-04	0.
PFXX ..	.12662E-06	.12662E-06	0.
PFYY ..	.27693E-07	.27693E-07	0.
PFZZ ..	.60892E-07	.60892E-07	0.

Figure 6-1 – Typical Listing of Store-Parameter Data from Vibration-Analysis Module.

```
                    CONSTRAINT EQS.

                       G MATRIX

 .5534000E+00  -.2881000E+00  -.1000000E+01   .1000000E+01  0.
0.             0.             0.             0.             0.
0.             0.             0.
-.8329000E+00  .9567600E+00  0.             0.             0.
0.             0.             0.             0.             0.
0.             0.             0.
0.             0.             0.             0.              .1000000E+01
-.1000000E+01  0.             0.             0.             0.
0.             0.             0.
0.             0.             0.             0.             0.
0.              .2588000E+00   .7420000E+00   .1000000E+01  -.7138000E+00
-.2865000E+00   .8503000E+00   .1474000E+00
0.             0.             0.             0.             0.
0.             -.9659000E+00  -.6704000E+00  0.              .7003000E+00
0.             0.             0.
0.             0.             0.             0.             0.
0.             0.             0.             0.             0.
 .9581000E+00   .5264000E+00  -.9891000E+00

                       B VECTOR

 .5331000E+00   .2647000E+00  -.3313500E+00   .9459500E+00   .1500000E+01
-.5000000E+00  -.8500000E-01   .1499000E+00   .1000000E+01  -.1350000E-01
 .2784000E+00   .8439000E+00   .4776000E+00
```

Figure 6-2 - Typical Listing of:

- G Matrix - Components of Unit Normal Vectors Pointing Outward from Search Space to Each Constraint Plane (Row Number Defines Component Direction; Column Number Defines Constraint Plane)

- b Vector - Scaled Distance from Origin to Each Constraint Plane in Direction of Unit Normal Vector.

Prior to entering the eigenvalue analysis for the first analysis cycle, the dynamics-model mass matrix that was entered as a separate data file (see Subsection 5.1) is listed.[1] This output, partially illustrated in Figure 6-3, would be the final mass matrix used for the eigenvalue analysis in the case of an analysis-only run (KLUE(7) = 0 in input-data Item 6 for the main program). However, for a store-search run (KLUE(7) = 7), the elements in this mass matrix that correspond to the store degrees of freedom are replaced subsequent to the listing by new elements calculated from the data in Figure 6-1 according to their analytical definitions contained in Reference 4, Eq. (4-2), page 4-3.[2] The replacement elements, illustrated in Figure 6-4, are listed immediately after the original total mass matrix for the first analysis cycle in a search, and updated values for these elements are listed in each subsequent analysis cycle as the search progresses.

At the conclusion of the eigenvalue analysis, the frequencies of the flexible modes are listed adjacent to modal indices that begin with 1 for the first flexible mode (see Figure 6-5(a)). In a subsequent listing of mode shapes, rigid-body modes are given along with the flexible modes if KLUE(38) in the main-program input data is 38 (see Figure 6-5(b)). Here, the modal-index values begin with 1 for the first rigid-body mode, and the previous flexible-mode indices have been incremented by the number of rigid-body modes. This combined-mode indexing system is followed throughout the remainder of the output from the vibration-analysis module.

6.2 - FLUTTER-ANALYSIS MODULE

A typical listing from the first page of output from the flutter-analysis module is shown in Figure 6-6. Here, the modal indices are changed again, this time based on the modes remaining following the selection process defined by Item 14 of the flutter-analysis-module input data.

---

[1] This listing is obtained from search runs only. However, an equivalent listing, produced immediately after reading the mass matrix, is provided by setting KLUEV(8) = 8.

[2] Modifications to Reference 4, including Eq.(4-2), are discussed in Subsection 5.1.

MATRIX NAME= REF MASS (206 X 206) PRINT LOWER TRIANGLE
(DYNAMIC MASS MATRIX ENTERING CURRENT FOP RUN - DOES NOT REFLECT STORE REDESIGN)

ROW	COL	VALUE	ROW	COL	VALUE	ROW	COL	VALUE
1	1	2.699999E+01						
2	2	2.699999E+01						
3	3	2.699999E+01						
4	4	4.749995E+02						
5	3	4.047360E+00	5	5	2.060606E+03			
6	2	4.047360E+00	6	6	2.460606E+03			
					⋮			
170	168	-1.923599E+03	170	170	2.952039E+04			
171	167	1.923599E+03	171	169	3.984463E+02	171	171	6.649581E+04
172	168	3.984463E+02	172	170	-5.578250E+03	172	172	3.747545E+04
173	173	9.999996E-02						
174	174	9.999996E-02						
175	175	9.999996E-02						
176	174	-1.519999E+00	176	176	2.410397E+01			
177	173	1.519999E+00	177	175	4.199950E-01	177	177	2.586791E+01
178	174	4.199950E-01	178	176	-6.383921E+00	178	178	2.763956E+00
179	179	9.999996E-02						
180	180	9.999996E-02						
					⋮			
188	184	2.033520E+03	188	186	3.984800E+02	188	188	6.966169E+04
189	185	3.984800E+02	189	187	-5.897504E+03	189	189	3.747565E+04
190	190	9.999996E-02						
191	191	9.999996E-02						
192	192	9.999996E-02						
193	191	-8.300000E-01	193	193	7.889000E+00			
194	190	8.300000E-01	194	192	-3.599898E-01	194	194	9.184927E+00
[illegible]	191	-3.599898E-01	195	193	2.987916E+00	195	195	2.295925E+00
196	196	9.999996E-02						
[illegible]	197	9.999996E-02						
					⋮			

Figure 6-3 - Typical Listing from Vibration-Analysis Module of Dynamics-Model Mass Matrix as Entered via Separate Data File.

NEW MASS MATRIX FOR STORE NUMBER 1

	173	174	175	176	177	178
173	3.00656E+03	0.	0.	0.	3.90853E+04	0.
174	0.	3.00656E+03	0.	-3.90853E+04	0.	-6.42686E+04
175	0.	0.	3.00656E+03	0.	-6.42686E+04	0.
176	0.	-3.90853E+04	0.	5.08110E+05	0.	8.35491E+05
177	3.90853E+04	0.	-6.42686E+04	0.	8.25192E+06	0.
178	0.	-6.42686E+04	0.	8.35491E+05	0.	7.74381E+06

NEW MASS MATRIX FOR STORE NUMBER 2

	190	191	192	193	194	195
190	3.50000E+03	0.	0.	0.	4.55000E+04	0.
191	0.	3.50000E+03	0.	-4.55000E+04	0.	2.25702E+04
192	0.	0.	3.50000E+03	0.	2.25702E+04	0.
193	0.	-4.55000E+04	0.	5.91501E+05	0.	-2.93412E+05
194	4.55000E+04	0.	2.25702E+04	0.	1.02370E+07	0.
195	0.	2.25702E+04	0.	-2.93412E+05	0.	9.64555E+06

Figure 6-4 - Typical Listing from Vibration-Analysis Module of Replacement Mass-Matrix Elements for Store Degrees of Freedom.

M	FREQUENCIES, [illegible]
1	3.9294
2	4.0290
3	4.6218
4	5.3397
5	5.6753
6	6.5417
7	6.9676
8	9.7598
9	12.7780
10	16.6507
11	23.3296
12	26.8053
13	27.4541
14	34.4882

(a) Frequencies

NORMALIZED EIGENVECTORS FOR ALL VIBRATION-ANALYSIS DEGREES OF FREEDOM (ABSOLUTE MOTION)
RIGID-BODY MODES (IF REQUESTED) FOLLOWED BY FLEXIBLE MODES

IOLD M =	1	2	3	4	5	6
1	1.000000E+00	0.	-1.800000E+00	-1.739804E-02	2.347491E-02	-1.482914E-02
2	0.	0.	0.	1.014149E-02	7.237056E-03	-2.126750E-02
3	0.	1.000000E+00	2.044000E+02	-9.910522E-01	1.070594E-01	1.000000E+00
4	0.	0.	0.	-6.062076E-03	6.793717E-04	6.376856E-03
5	0.	0.	1.000000E+00	-2.006206E-03	2.225044E-04	3.247970E-03
6	0.	0.	0.	-6.251577E-05	1.063260E-04	-1.047949E-04
7	1.000000E+00	0.	-2.000000E+00	-1.628424E-02	2.221831E-02	-1.428427E-02
8	0.	0.	0.	9.226769E-03	6.870764E-03	-1.950122E-02
9	0.	1.000000E+00	1.996000E+02	-9.126274E-01	9.828193E-02	9.121873E-01
10	0.	0.	1.000000E+00	-1.992893E-03	2.209923E-04	3.228390E-03
11	0.	0.	0.	-6.275545E-05	1.063441E-04	-1.044249E-04
12	1.000000E+00	0.	-2.200000E+00	-1.496622E-02	2.063148E-02	-1.342992E-02
13	0.	0.	0.	8.413214E-03	6.365231E-03	-1.762924E-02
14	0.	1.000000E+00	1.936000E+02	-8.145250E-01	8.730393E-02	8.028206E-01
15	0.	0.	1.000000E+00	-1.825949E-03	2.020921E-04	2.988212E-03
16	1.000000E+00	0.	-2.399990E+00	-1.387229E-02	1.940817E-02	-1.291715E-02
17	0.	0.	0.	7.563235E-03	6.005041E-03	-1.598009E-02
18	0.	1.000000E+00	1.890000E+02	-7.422045E-01	7.921465E-02	7.230063E-01
19	0.	0.	1.000000E+00	-1.662629E-03	1.836264E-04	2.756145E-03
20	1.000000E+00	0.	-2.800000E+00	-1.184848E-02	1.720157E-02	-1.208988E-02
21	0.	0.	0.	5.967880E-03	5.362475E-03	-1.300157E-02
22	0.	1.000000E+00	1.807000E+02	-6.198396E-01	6.553752E-02	5.903094E-01
23	0.	0.	1.000000E+00	-1.381520E-03	1.518546E-04	2.358439E-03
24	1.000000E+00	0.	-2.899990E+00	-1.126857E-02	1.654364E-02	-1.179712E-02

(b) Mode Shapes

Figure 6-5 - Typical Listing from Vibration-Analysis Module of Flexible-Mode Frequencies and Rigid-Body and Flexible Mode Shapes.

GENERALIZED MASS, FREQUENCY, AND GENERALIZED MODAL STIFFNESS

GENERALIZED MASS, LB

MODE	MODE= 1	2	3	4	5	6
1	2.484186E+04	2.863469E+06	-1.623448E-10	1.506351E-11	1.646185E-10	9.299583E-11
2	2.863469E+06	5.812916E+08	-1.997250E-08	1.693934E-09	2.048546E-08	-7.245944E-09
3	-1.623448E-10	-1.997250E-08	2.549499E+03	-4.514433E-11	1.466702E-10	1.177369E-10
4	1.506351E-11	1.693934E-09	-4.514433E-11	6.897471E+02	-9.860557E-12	7.102718E-11
5	1.646185E-10	2.048546E-08	1.466702E-10	-9.860557E-12	8.351531E+02	-2.399645E-10

MODE	FREQUENCY CYC/SEC	FREQUENCY RAD/SEC	DAMPING NO UNITS
1	5.000000E-03	3.141592E-02	2.000000E-02
2	5.000000E-03	3.141592E-02	2.000000E-02
3	3.929363E+00	2.468891E+01	2.000000E-02
4	4.028988E+00	2.531487E+01	2.000000E-02
5	4.621816E+00	2.903972E+01	2.000000E-02

COMPLEX GENERALIZED MODAL STIFFNESS, (REAL, IMAG), LB/IN

MODE	MODE= 1	2	3
1	(2.4518E+01, 4.9036E-01)	(2.8261E+03, 0.)	(0. , 0.)
2	(2.8261E+03, 0.)	(8.9947E+05, 1.7989E+04)	(0. , 0.)
3	(0. , 0.)	(0. , 0.)	(1.5540E+06, 3.1081E+04)
4	(0. , 0.)	(0. , 0.)	(0. , 0.)
5	(0. , 0.)	(0. , 0.)	(0. , 0.)

Figure 6-6 - Typical Listing of Modal Data from Flutter-Analysis Module.

If automatic mode elimination based on ratios of generalized forces to generalized masses has been selected (LC(38) = 1 in Item 4 of flutter-analysis-module input data), the output illustrated in Figure 6-7 is obtained. The data provided in Item 51B, along with the two additional velocities calculated by the program, are listed at the top of the figure, followed by the results of the mode-elimination test.

Typical CalComp plots of flutter-analysis results are shown in Figures 6-8 through 6-10. The first of these figures is representative of output from a p-k flutter solution that is done either during the first analysis cycle of a store-search run or during an analysis-only run. The second plot illustrates the more abbreviated p-k output obtained from a second or subsequent analysis cycle of a store-search run. A k-method flutter solution is shown in the third of this series of figures.

6.3 - SEARCH MODULE

The output from the store-parameter search module is discussed almost in its entirety, since this ESP output is completely new compared to FASTOP.[1]

After repeating the flutter speed (in knots equivalent airspeed) that was previously listed in the output from the flutter-analysis module, the derivatives of the flutter speed with respect to the various store parameters are listed, together with several intermediate results (see Figure 6-11). This output is grouped according to store-station number, with the derivatives being listed first using the same store-parameter notation that was discussed previously in connection with the vibration-analysis module (cf. Figure 6-1). The three arrays immediately thereafter are the matrices in Eq. (4-5), page 4-4, of Reference 4; S1, S2, and S3 in the listing correspond to S_x, S_y, and S_z in the reference. The U and V vectors given next are the flutter eigenvector and its associated row vector in physical coordinates for the store

---

[1] The title page for this module, however, retains the previous FLUTTER OPTIMIZATION MODULE wording.

MODAL ELIMINATION BASED ON RATIO OF GENERALIZED FORCES TO GENERALIZED MASSES

CUT-OFF RATIO = 2.500E-03

VELOCITIES CHECKED (KNOTS, TAS): 3.375E+02 4.500E+02 5.625E+02

MODE	FREQUENCY	MAX. VEL. TESTED	DETERMINANT ELEMENT CONTRIBUTION FOR MAXIMUM VELOCITY TESTED: GEN. FORCE	GEN. MASS	RATIO	DELETED?
1	3.142E-02	3.375E+02	7.256E+05	2.468E+04	2.940E+01	NO
2	3.142E-02	3.375E+02	2.292E+13	5.801E+08	3.950E+04	NO
3	2.493E+01	3.375E+02	2.729E+01	9.920E+02	2.751E-02	NO
4	2.547E+01	3.375E+02	2.308E+01	1.374E+03	1.680E-02	NO
5	2.914E+01	3.375E+02	8.899E+01	8.608E+02	1.034E-01	NO
6	3.370E+01	3.375E+02	1.047E+02	1.801E+03	5.813E-02	NO
7	3.617E+01	3.375E+02	3.499E+01	1.724E+03	2.030E-02	NO
8	4.185E+01	3.375E+02	3.314E+01	1.395E+03	2.376E-02	NO
9	4.438E+01	3.375E+02	7.697E+00	9.993E+02	7.702E-03	NO
10	6.152E+01	3.375E+02	4.347E+01	1.011E+03	4.299E-02	NO
11	8.062E+01	3.375E+02	3.383E+01	1.017E+03	3.328E-02	NO
12	1.054E+02	5.625E+02	1.596E+00	7.245E+02	2.204E-03	YES
13	1.476E+02	3.375E+02	3.407E+01	1.346E+03	2.532E-02	NO
14	1.703E+02	3.375E+02	4.476E+01	8.469E+02	5.285E-02	NO
15	1.726E+02	3.375E+02	7.035E+01	1.183E+03	5.949E-02	NO
16	2.175E+02	3.375E+02	1.389E+01	5.461E+02	2.543E-02	NO

Figure 6-7 - Typical Listing of Automatic-Mode-Elimination Results from Flutter-Analysis Module.

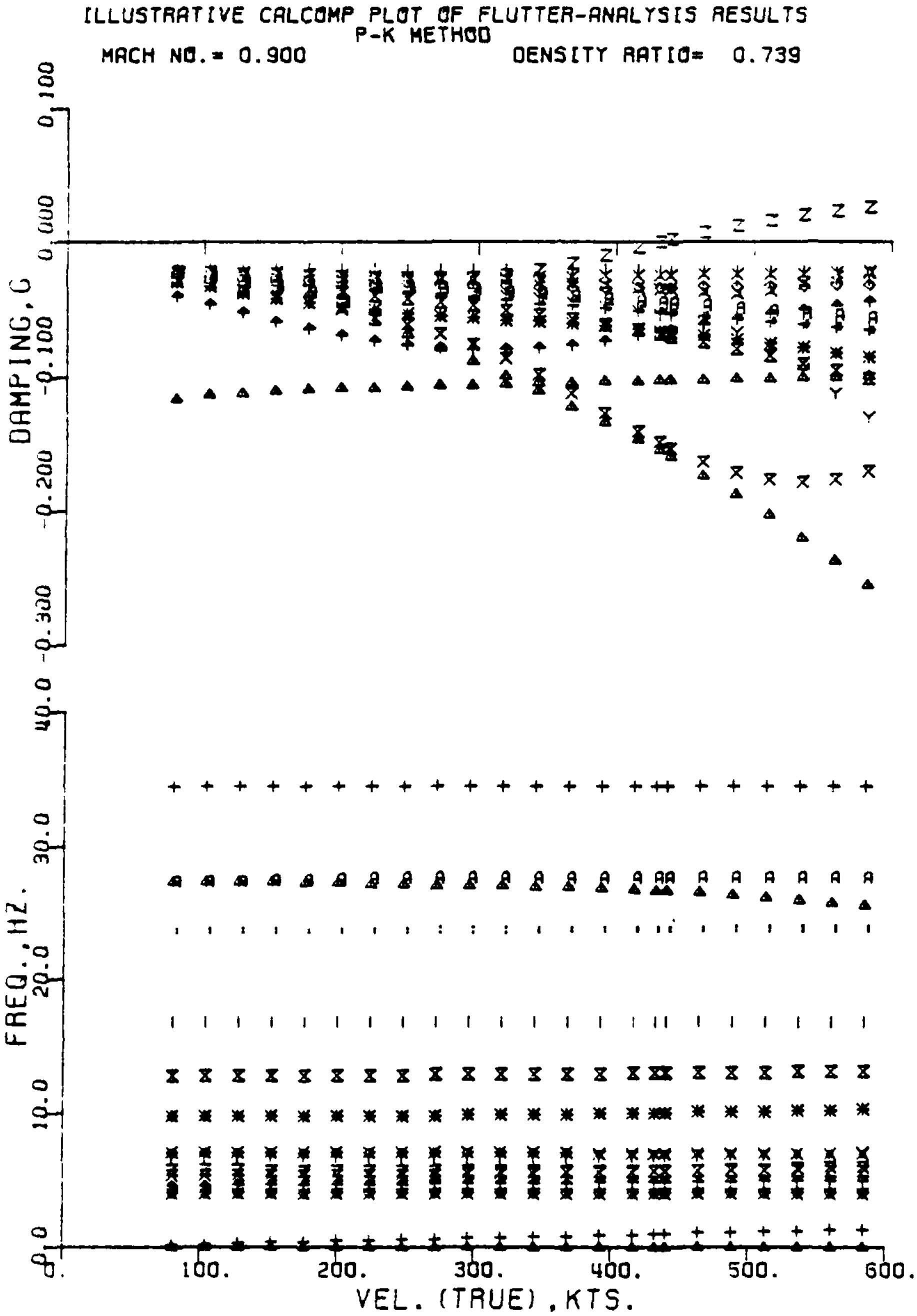

Figure 6-8 - Typical CalComp Plot of p-k Flutter-Analysis Results from Either an Analysis-Only Run or the First Analysis Cycle of a Store-Search Run.

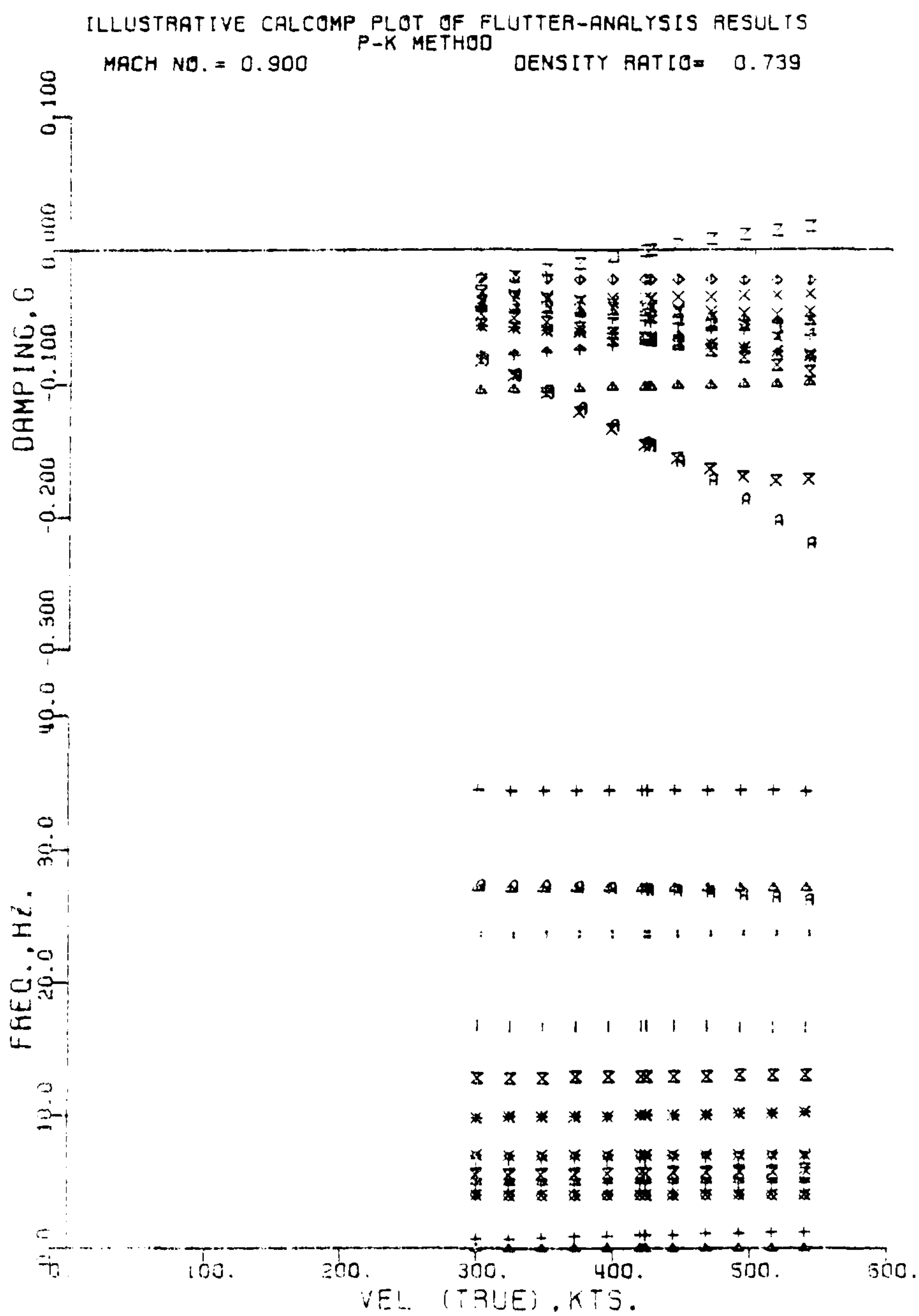

Figure 6-9 - Typical CalComp Plot of p-k Flutter-Analysis Results from a Second or Subsequent Analysis Cycle of a Store-Search Run.

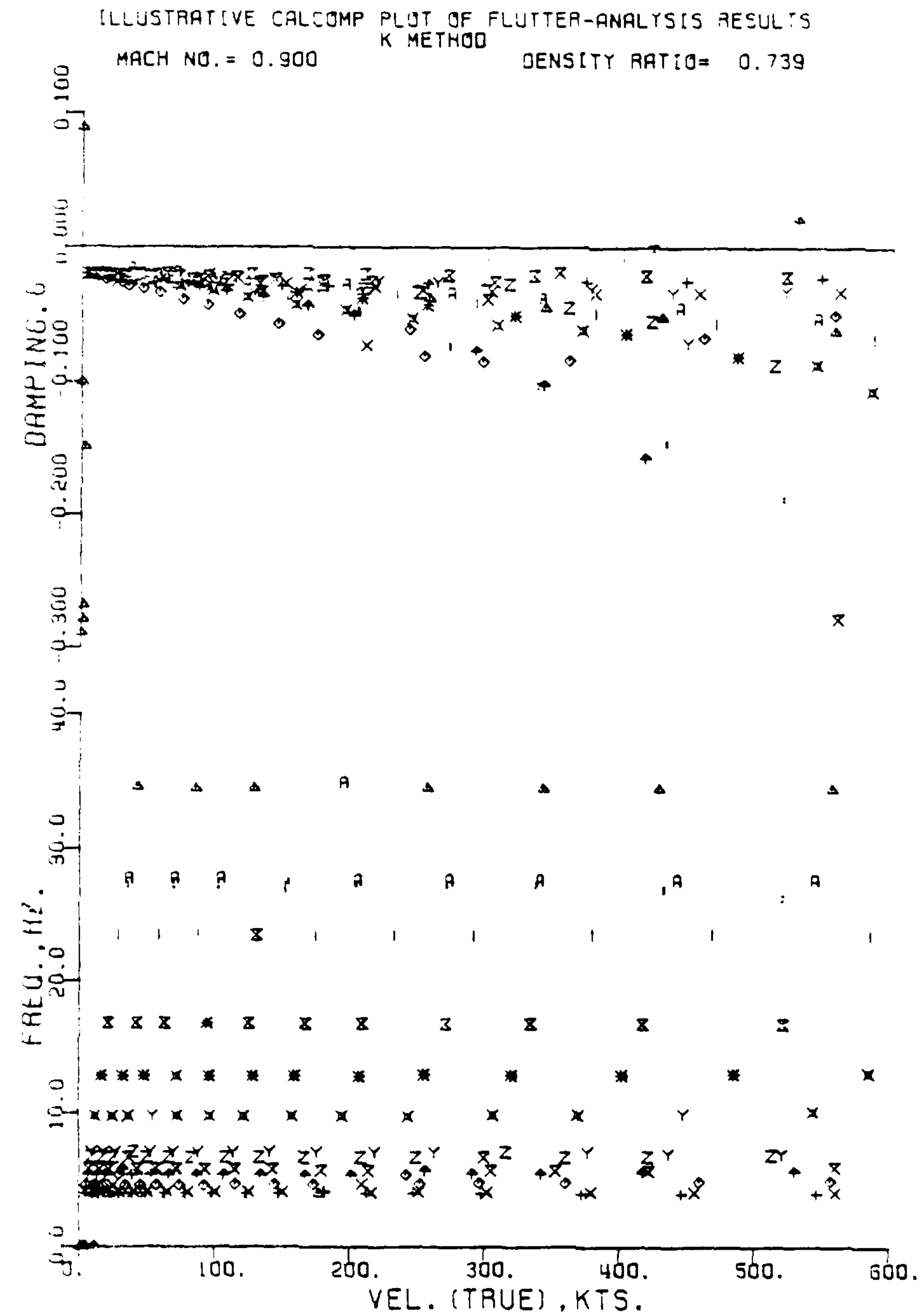

Figure 6-10 - Typical CalComp Plot of k Flutter-Analysis Results.

CURRENT FLUTTER SPEED = 363.9736 KNOTS

DERIVATIVES FOR STORE NUMBER 1

W	9.01997E-03
IXX	1.76939E-05
IYY	-2.41730E-06
IZZ	-2.41730E-06
SX	-1.49667E+00
SY	3.04009E+00
SZ	5.22566E-01
PFX	-5.06688E+05
PFY	1.95572E+05
PFZ	-2.42227E+05
PFXX	3.30083E+07
PFYY	3.63398E+08
PFZZ	5.51275E+08

STORE 1 DERIVATIVES FOR S1

1	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	-3.00656E+03
3	0.	0.	0.	0.	-3.00656E+03	0.
4	0.	0.	0.	0.	0.	3.90853E+04
5	0.	0.	-3.00656E+03	0.	1.28537E+05	0.
6	0.	-3.00656E+03	0.	3.90853E+04	0.	1.28537E+05

Figure 6-11 - Typical Listing from Search Module of Flutter Speed and Flutter-Speed Derivatives, Including Intermediate Results (1 of 2).

```
STORE 1 DERIVATIVES FOR S2
1   0.           0.           0.           0.           0.           3.00656E+03
2   0.           0.           0.           0.           0.           0.
3   0.           0.           0.           3.00656E+03  0.           0.
4   0.           0.           3.00656E+03  0.           -6.42686E+04 0.
5   0.           0.           0.           -6.42686E+04 0.           -3.90853E+04
6   3.00656E+03  0.           0.           0.           -3.90853E+04 0.

STORE 1 DERIVATIVES FOR S3
1   0.           0.           0.           0.           3.00656E+03  0.
2   0.           0.           0.           -3.00656E+03 0.           0.
3   0.           0.           0.           0.           0.           0.
4   0.           -3.00656E+03 0.           7.81706E+04  0.           6.42686E+04
5   3.00656E+03  0.           0.           0.           7.81706E+04  0.
6   0.           0.           0.           6.42686E+04  0.           0.

 U FLUTTER VECTORS
    4.76167E-02  2.01768E-02  7.53173E-02  -6.82494E-02  -5.53426E-02  7.41201E-02
   -3.89291E-03  3.57966E-03  6.59918E-03   2.82365E-03   2.90725E-03 -2.54965E-03

 V FLUTTER VECTORS
    2.77834E-05 -7.96825E-06  4.48488E-05   2.01439E-05  -3.87195E-05 -2.48747E-05
   -2.33209E-06 -1.03575E-06  3.70822E-06  -1.44582E-06   1.66386E-06  8.39272E-07

CSCL =   -2.54895E+01

DERIVATIVES FOR STORE NUMBER   2
W        -3.88106E-02
IXX      -4.55362E-05
IYY       5.26764E-06
              •
              •
              •
```

Figure 6-11 - Typical Listing from Search Module of Flutter Speed and Flutter-Speed Derivatives, Including Intermediate Results (2 of 2).

been saved from the previous cycle. The data set that should be used for the restart is the last one that contains information corresponding to an analysis cycle in which the flutter speed was decreased. Thus, if the next-to-the-last analysis cycle exhibited a lower flutter speed than the one before, the last data set in the TAPE48 file should be used as an input file (via TAPE47) in the next job submission.

The TAPE48 file is similar to the TAPE40 file to the extent that, for the most part, it too consists of selected portions of the printed output. However, as seen in Figure 6-18, the TAPE48 file is not annotated, and therefore a brief discussion follows in which the lines in Figure 6-18 are related to corresponding lines in Figures 6-12, 6-13, 6-15, and 6-16. All these figures contain output from the same job and analysis cycle.

The first two lines in Figure 6-18 correspond to the PREVIOUS SCALED VARIABLES in Figure 6-13, and immediately thereafter is the OLD INVERSE MATRIX in Figure 6-12. The next array is a set of previous scaled derivatives. This array does not have an exact counterpart in Figures 6-12 and 6-13, but it would have been printed as the SCALED DERIVATIVES in the version of Figure 6-13 corresponding to the previous analysis cycle. The next two lines, with one number per line, are the step size and the flutter speed for the previous cycle. These would have been listed in the version of Figure 6-13 for that cycle.

The next group of data in Figure 6-18 consists of the number of active and inactive constraints at the end of the previous cycle, and corresponds to the information shown at the top of Figure 6-12. Next, the previous-cycle MOMENT MATRIX in Figure 6-12 is listed. The final line in Figure 6-18 contains the number of new constraints introduced by the previous step, followed by the indices of these constraints. If the first number is zero, the second number is the index of the nearest inactive constraint in the direction of the step. This would have been listed as JNEW(1) near the bottom of the version of Figure 6-15 for the previous analysis cycle.

```
 7.38919E-01   5.08220E-01   1.00308E+00   1.00000E+00   1.00000E+00
-1.74846E-01
 1.00000E+00   0.            0.            0.            0.
 0.
 0.            1.00000E+00   0.            0.            0.
 0.
 0.            0.            1.00000E+00   0.            0.
 0.
 0.            0.            0.            1.00000E+00   0.
 0.
 0.            0.            0.            0.            1.00000E+00
 0.
 0.            0.            0.            0.            0.
 1.00000E+00
-4.11895E-03  -1.44481E-01  -7.48922E-02  -1.38403E-02  -3.17372E-02
-9.49678E-03
                                     1.000
                                   371.097
  3    10
  2     9    10     0     0     0     0     0     0     0
  0     0     0
  1     3     4     5     6     7     8    11    12    13
  0     0     0
 .1001611E+01  0.            0.
0.              .2038927E+01  .1455487E+01
0.              .1455487E+01  .2039068E+01
  0     4
```

Figure 6-18 - Listing of Typical Restart File from Search Module

```
 NEW INVERSE HESSIAN AND DIRECTION
 9.98846E-01   1.30815E-02   1.90237E-03  -2.28088E-02   1.52897E-02
-1.41320E-02
 1.30815E-02   8.51723E-01  -2.15632E-02   2.58536E-01  -1.73308E-01
 1.60185E-01
 1.90237E-03  -2.15632E-02   9.96864E-01   3.75975E-02  -2.52032E-02
 2.32948E-02
-2.28088E-02   2.58536E-01   3.75975E-02   5.49218E-01   3.02178E-01
-2.79297E-01
 1.52897E-02  -1.73308E-01  -2.52032E-02   3.02178E-01   7.97437E-01
 1.87225E-01
-1.41320E-02   1.60185E-01   2.32948E-02  -2.79297E-01   1.87225E-01
 8.26952E-01
 3.74836E-02  -1.07947E-01   3.40077E-03  -5.46144E-02  -4.40454E-03
-2.52630E-02

  SCALED DERIVATIVES ARE
 3.33739E-02  -6.13634E-02   1.01752E-02  -1.35837E-01   5.00426E-02
-7.55873E-02

  PREVIOUS SCALED VARIABLES ARE
 7.68919E-01   5.08220E-01   1.00308E+00   1.00000E+00   1.00000E+00
-1.74846E-01

  PRESENT SCALED VARIABLES ARE
 8.12585E-01   5.21368E-01   1.07797E+00   1.00000E+00   1.00000E+00
-1.65349E-01
        NORM OF SCALED GRADIENT VECTOR =      1.7791E-01

  NEW SCALED VARIABLES ARE
 8.11172E-01   5.20943E-01   1.07692E+00   1.00000E+00   1.00000E+00
-1.57530E-01


  ***** NEW STORE PARAMETERS *****

PARA STORE NO. 1  STORE NO. 2  STORE NO.


   W 3.00134E+03  3.50000E+03
  IX 1.00000E+00  1.00000E+00
  IY 6.37000E+06  9.50000E+06
  IZ 6.37000E+06  9.50000E+06
  RX 2.13587E+01 -6.14367E+00
  RY 0.           0.
  RZ 1.30000E+01  1.30000E+01
  FX 1.11620E-05  4.73867E-06
  FY 3.91623E-05  3.94256E-05
  FZ 5.35534E-05  1.72570E-05
 FXX 1.32900E-07  1.26623E-07
 FYY 3.01537E-08  2.76931E-08
 FZZ 6.17304E-08  6.08923E-08

        CURRENT STEP SIZE =          1.000

        CURRENT FLUTTER SPEED =    363.974   KNOTS
```

Figure 6-17 - Listing of Typical Summary File from Search Module (2 of 2)

```
DERIVATIVES FOR STORE NUMBER   1
W          9.01997E-03
IXX        1.76939E-05
IYY       -2.41730E-06
IZZ       -2.41730E-06

DERIVATIVES FOR STORE NUMBER   2
W         -3.88106E-02
IXX       -4.55362E-05
IYY        5.26764E-06
IZZ        5.26764E-06

 STORE PARAMETERS FOR REDESIGN CYCLE NO.   2
 THE FLUTTER SPEED HAS BEEN DECREASED BY     7.1235 KNOTS.
PREVIOUS MOVE

4.36657E-02   1.31486E-02   7.48922E-02   0.            0.
9.49678E-03
DELTA GRAD

3.74929E-02   8.31172E-02   8.50673E-02  -1.21997E-01   8.17798E-02
-6.60905E-02

OLD INVERSE HESSIAN
1.00000E+00   0.            0.            0.            0.
0.
0.            1.00000E+00   0.            0.            0.
0.
0.            0.            1.00000E+00   0.            0.
0.
0.            0.            0.            1.00000E+00   0.
0.
0.            0.            0.            0.            1.00000E+00
0.
0.            0.            0.            0.            0.
1.00000E+00
HOLD*(DELTA GRAD)

3.74929E-02   8.31172E-02   8.50673E-02  -1.21997E-01   8.17798E-02
-6.60905E-02
Z= DELTAX-HOLDG

6.17284E-03  -6.99686E-02  -1.01752E-02   1.21997E-01  -8.17798E-02
7.55873E-02
CK AND Z2 =     -.33017E-01       .32322E-01
```

Figure 6-17 - Listing of Typical Summary File from Search Module (1 of 2)

```
  NEW SCALED VARIABLES ARE
 8.11172E-01   5.20943E-01   1.07692E+00   1.00000E+00   1.00000E+00
-1.57530E-01


  ***** NEW STORE PARAMETERS *****

PARA STORE NO. 1  STORE NO. 2  STORE NO.

   W 3.00134E+03  3.50000E+03
  IX 1.00000E+00  1.00000E+00
  IY 6.37000E+06  9.50000E+06
  IZ 6.37000E+06  9.50000E+06
  RX 2.13587E+01 -6.14367E+00
  RY 0.           0.
  RZ 1.30000E+01  1.30000E+01
  FX 1.11620E-05  4.73867E-06
  FY 3.91623E-05  3.94256E-05
  FZ 5.35534E-05  1.72570E-05
 FXX 1.32900E-07  1.26623E-07
 FYY 3.01537E-08  2.76931E-08
 FZZ 6.17304E-08  6.08923E-08

      CURRENT STEP SIZE =          1.000        .

      CURRENT FLUTTER SPEED =    363.974   KNOTS
```

Figure 6-16 - Typical Listing of Search-Module Output Including New Store Parameters in Terms of Physical Units

Below PG, the inactive constraint indices for the current search point are listed, followed by several quantities defining the next search step. JNEW(1) is the index of the nearest inactive constraint plane in the direction of the search step. STEPS is the step size required to reach that constraint, and STEPSS is the minimum of the two quantities STEPS and 1. VALU is equal to 0.33/PNORM, and STEP, which is the final step size, is the minimum of the two quantities VALU and STEPSS. A further discussion of the step-size determination procedure is given in Reference 4, Subsection 3.4, page 3-9 and 3-10.

In Figure 6-16, the new scaled variables have been converted to physical store-parameter values. Also, the scaled step size and the value of the flutter speed before the new step are repeated.

This concludes the discussion of the printed output usually obtained from the search module. However, as implied in this discussion, additional output will be printed in some situations, such as search steps that require a line search (see page 3-10 of Reference 4), that involve a move off a constraint plane, or that terminate at a local minimum.

In addition to the printed output, the search module also provides two formatted disk files via TAPE40 and TAPE48 as discussed in Section 4. The first file contains selected portions of the printed output, including annotations, and is intended to facilitate a quick review of progress made during a search, in preparation for a restart of the search if necessary. A comparison of the illustrative example in Figure 6-17 with the output in the previous six figures provides a complete description of its contents. Although not shown in the figure, the summary material in a TAPE40 file includes results for all the analysis cycles executed in the run from which it is generated.

The file obtained via TAPE48 consists of a series of results, such as those shown in Figure 6-18, that can be used to restart a search in a manner that takes advantage of the previously computer inverse-Hessian matrix. A new set of potential restart data is obtained from each analysis cycle except the first, and the information that is written in each cycle is data that has

```
        ENTERING HYPER

        DELX TRANSPOSE

-1.41285E-03  -4.25439E-04  -1.05259E-03   1.33227E-15   8.32667E-17
 7.81928E-03

        SK*GM*LAM

 3.60708E-02  -1.08372E-01   2.34818E-03  -5.46144E-02  -4.40454E-03
-1.74437E-02

        SK*GRN

 3.74836E-02  -1.07947E-01   3.40077E-03  -5.46144E-02  -4.40454E-03
-2.52630E-02

        EXIT HYPER

        LAM( 3) = -3.32391E-02    LMK( 3, 3) =  4.06989E+00    BETA = -4.08353E-03    PNORM =  8.02659E-03

        PG = -6.22794E-04

        ENTERING INSECT
        NOTACT =     1    3    4    5    6    7    8   11   12   13

JNEW(1) =    12 STEPSS =  1.0000E+00 STEPS =  1.9591E+01 VALU =  4.1113E+01 STEP =  1.0000E+00

        EXIT INSECT

        LEAVING CONSTR
```

Figure 6-15 - Typical Listing of Search-Module Scaled Output Defining Constrained Search Step, Convergence-Test Parameters, and Step-Size Parameters.

inverse-moment matrix is calculated and listed once to reflect the new inverse-Hessian matrix; this is the last of the inverse-moment-matrix listings shown in Figure 6-14. At the bottom of Figure 6-14, the Lagrange multipliers obtained from Eq. (3-19) on page 3-9 of Reference 4 are listed.

Some scaled-variable results from a constrained search step are shown at the top of Figure 6-15. The increments to the search variables, as given by the first of Eqs. (3-20) on page 3-9 of Reference 4, are listed first, followed by the contributions to these increments of each of the two terms on the right side of this equation.

The line below these arrays is associated with constraint-plane and local-minimum tests. The first number, LAM(J), is the algebraically largest nonzero Lagrange multiplier, and the second, LMK(J,J) is the corresponding diagonal element of the inverse-moment matrix. The third number is defined by BETA = ½ * LAM(J) * |LMK(J,J)|. The fourth number, PNORM, is the square root of the sum of the squares of the search-variable increments. A value of PNORM less than or equal to BETA indicates that the constraint plane corresponding to the index, J, in the above equation for BETA should be dropped. The scaled-variable increments are then recomputed with the correspondingly revised active-constraint matrix, G. The values of BETA and PNORM also are used in the first and second parts, respectively, of the three-part test shown on page 3-11 of Reference 4 to determine if a local constrained minimum has been reached. (Since the factor ½ and the inverse-moment element in the expression for BETA are together of order of magnitude 1, and since the Lagrange multiplier used in BETA is the largest of the Lagrange multipliers, the tests of the Lagrange multipliers shown in Eq. (3-27) of Reference 4 are approximately equivalent to a test of BETA).

The next quantity, PG, in Figure 6-15 is the scalar product of the scaled search-variable increments listed at the top of the figure and the scaled flutter-speed derivatives in Figure 6-13. For a positive or zero value of this quantity, the move represented by these increments is ineffective, i.e., the flutter speed would be increased or remain constant. In this situation, a new search direction is computed based on the projection of the gradient on the active constraint planes.

```
ENTERING SUBROUTINE CONSTR


ENTERING SETJGL


CONSTRAINT FUNCTIONS AT XN

-5.30876E-01   1.85599E-05  -4.37569E-01  -1.77031E-01  -4.96921E-01
-5.03079E-01  -6.22100E-01  -7.83000E-02   0.            -4.99600E-16
-7.32420E-01  -8.56390E-02  -1.57260E-01

ENTERING ADDCON, CONSTRAINT   9 TO BE ADDED

 INVERSE MOMENT MATRIX,  LMK

  1.0016E+00  0.
  0.          1.0000E+00

 JSET =      2     9

ENTERING ADDCON, CONSTRAINT  10 TO BE ADDED

 INVERSE MOMENT MATRIX,  LMK

  1.0016E+00  0.          0.
  0.          2.0389E+00  1.4555E+00
  0.          1.4555E+00  2.0391E+00

 JSET =      2     9    10

 JSET =      2     9    10


INVERSE MOMENT MATRIX,  LMK

  1.0016E+00  0.          0.
  0.          2.0389E+00  1.4555E+00
  0.          1.4555E+00  2.0391E+00


ENTERING LAGMUL

 LAGRANGE MULTIPLIERS,  LAM

  -1.3727E-01 -4.6189E-02 -4.5319E-02

 EXIT LAGMUL
```

Figure 6-14 - Typical Listing of Search-Module Output Pertaining to Introduction of Constraints (results shown are for different analysis cycle than those in other figures containing search-module output).

scale factors provided as input data via Items 8I and 8K of the vibration-analysis module. As mentioned previously in the discussion of Figure 6-12, this and other scaled arrays contain elements only for the store parameters for which the input scale factors are nonzero. The sum of the squares of the scaled-derivative elements is shown at the bottom of Figure 6-13.

The array immediately after the new inverse Hessian in Figure 6-13 is the product of the latter array and the scaled-derivative array. The result is the direction array given by Eq. (3-6) on page 3-3 of Reference 4 (without the minus sign). The last array illustrated in Figure 6-13 defines the search point for which the analyses and derivative computations have just been completed. The immediately preceding array gives similar information for the previous analysis cycle. For the first cycle, the previous and present arrays are identical.

The next group of search-module output pertains to the introduction of constraints, and is illustrated in Figure 6-14. For a first pass through the search module, or if the number of active constraints was previously zero, the position of the present search point relative to the constraint planes is calculated by substituting the scaled variables into the expression on the left side of Eq. (3-1) on page 3-1 of Reference 4. The result of this calculation is the first array illustrated in Figure 6-14. A moderate-size negative value for an element indicates that the present search point is inside the search space with respect to the constraint plane having an index corresponding to that element. An element value greater than -0.001 is considered within the program to denote that the search point is on or outside the constraint plane corresponding to that element. In the sample output shown, constraints 2, 9, and 10 are active.

A projection of the search direction along the active constraints is performed as discussed in Subsection 3.3 of Reference 4. As each successive constraint is introduced (except the first), a listing is given of the inverse-moment matrix (see page 3-9 of Reference 4) corresponding to all the constraints that have been introduced to that stage of the calculations. If no new constraints are being introduced in a particular analysis cycle, the

```
    NEW INVERSE HESSIAN AND DIRECTION

  9.98846E-01   1.30815E-02   1.90237E-03  -2.28088E-02   1.52897E-02
 -1.41320E-02
  1.30815E-02   8.51723E-01  -2.15632E-02   2.58536E-01  -1.73308E-01
  1.60185E-01
  1.90237E-03  -2.15632E-02   9.96864E-01   3.75975E-02  -2.52032E-02
  2.32948E-02
 -2.28088E-02   2.58536E-01   3.75975E-02   5.49218E-01   3.02178E-01
 -2.79297E-01
  1.52897E-02  -1.73308E-01  -2.52032E-02   3.02178E-01   7.97437E-01
  1.87225E-01
 -1.41320E-02   1.60185E-01   2.32948E-02  -2.79297E-01   1.87225E-01
  8.26952E-01


  3.74836E-02  -1.07947E-01   3.40077E-03  -5.46144E-02  -4.40454E-03
 -2.52630E-02

    SCALED DERIVATIVES ARE
  3.33739E-02  -6.13634E-02   1.01752E-02  -1.35837E-01   5.00426E-02
 -7.55873E-02

    PREVIOUS SCALED VARIABLES ARE
  7.68919E-01   5.08220E-01   1.00308E+00   1.00000E+00   1.00000E+00
 -1.74846E-01

    PRESENT SCALED VARIABLES ARE
  8.12585E-01   5.21368E-01   1.07797E+00   1.00000E+00   1.00000E+00
 -1.65349E-01

         NORM OF SCALED GRADIENT VECTOR =      1.7791E-01
```

Figure 6-13 - Typical Listing of Search-Module Scaled Output Defining Search Variables, Derivatives, Inverse Hessian, and New Search Direction for Search Point Corresponding to Immediately Preceding Analysis Point.

The next two arrays in Figure 6-12 are the changes, relative to the previous search point, in the search variables and in the partial derivatives of the flutter speed with respect to the search variables. For these, as well as the subsequent arrays in Figure 6-12, the size of the arrays is determined by the number of nonzero scale factors entered in Item 81 of the search-module input data.

Next, the inverse-Hessian matrix, i.e., the inverse of the matrix of second partial derivatives of the flutter speed with respect to the search variables, is listed for the previous search point. Since two search steps are required to develop the inverse Hessian by the procedure used in ESP, the default identity matrix will be listed if the current search point was reached following the first search step.

Below the old inverse-Hessian matrix are several intermediate results obtained during the calculation of the updated version of this matrix. The approach used to calculate the inverse Hessian is discussed in Subsection 3.2 of Reference 4, and the final expressions used are given as Eqs. (3-12) on page 3-6 of that reference. First, the values of the second term in the second of Eqs. (3-12) is listed, and then the sum of both terms in that equation is given. The last two quantities are the value of c from the third of Eqs. (3-12), and the scalar product of the previous Z array (y in Eqs. (3-12)) with itself. The latter quantity is used in a comparison test with c to determine if the inverse-Hessian increment given by the second term in the first of Eqs. (3-12) will be unacceptably large. If it is, Z2 is used in place of c in this term. Messages are printed for this and other tests if a modification of the first of Eqs. (3-12) is appropriate.

The new inverse-Hessian array, generally obtained according to the first of Eqs. (3-12), is shown at the top of Figure 6-13. For the first entry into the search module, this will be the first output after that illustrated in Figure 6-11, and the new inverse Hessian will be the identity matrix. The scaled-derivative array, which is the third group of output in Figure 6-13, is obtained by combining the derivatives illustrated in Figure 6-11 with the

```
          STORE PARAMETERS FOR REDESIGN CYCLE NO.    2

AS RESTART BEGINS THERE ARE  3 ACTIVE CONSTRAINTS WITH THE FOLLOWING INDICES

   2     9    10     0     0     0     0     0     0     0
   0     0     0

AS RESTART BEGINS THERE ARE 10 INACTIVE CONSTRAINTS WITH THE FOLLOWING INDICES

   1     3     4     5     6     7     8    11    12    13
   0     0     0

THE INVERSE MOMENT MATRIX IS

 .1001611E+01  0.               0.
0.              .2038927E+01    .1455487E+01
0.              .1455487E+01    .2039068E+01
          THE FLUTTER SPEED HAS BEEN DECREASED BY      7.1235 KNOTS.

          ENTERING MURT

     PREVIOUS MOVE

  4.36657E-02   1.31486E-02   7.48922E-02   0.             0.
  7.49678E-03

     DELTA GRAD

  3.74929E-02   8.31172E-02   8.50673E-02  -1.21997E-01   8.17798E-02
 -6.60905E-02

     OLD INVERSE HESSIAN

  1.00000E+00   0.            0.            0.            0.
  0.
  0.            1.00000E+00   0.            0.            0.
  0.
  0.            0.            1.00000E+00   0.            0.
  0.
  0.            0.            0.            1.00000E+00   0.
  0.
  0.            0.            0.            0.            1.00000E+00
  0.
  0.            0.            0.            0.            0.
  1.00000E+00

     HOLD*(DELTA GRAD)

  3.74929E-02   8.31172E-02   8.50673E-02  -1.21997E-01   8.17798E-02
 -6.60905E-02

     Z = DELTAX-HOLDG

  6.17284E-03  -6.99686E-02  -1.01752E-02   1.21997E-01  -8.17798E-02
  7.35873E-02

     CK AND Z2 =      -.33017E-01        .32322E-01
```

Figure 6-12 - Typical Listing of Search-Module Output Defining Constraint Status, Search Progress, and Intermediate Results Required for Updating the Inverse-Hessian Matrix (Obtained Only After Second or Subsequent Analysis Cycle).

degrees of freedom (see Eq. (4-1), page 4-1, Reference 4). The vector components are listed as pairs of real and imaginary parts in an order corresponding to the store degree-of-freedom numbers (cf. Figure 6-4 and associated discussion). The units of the rotation degrees of freedom are rad./ft., assuming a normalization with respect to displacement. The quantity CSCI is defined by Eq. (9.7), page 107, of Reference 1, Volume 1; it is a repeat of the last listed item before the print-plots in the flutter-analysis module.

The next group of output to be described (see Figure 6-12) appears only after a search step has been taken, i.e., in a second or subsequent entry to the search module. At the top of the figure, the status of the search with respect to the various constraint planes is given. The numbering system corresponds to the order in which constraint planes are defined by means of either the groups of constraint-equation parameters entered in input-data items 8R and 8S if ITOC1 = 1, or the points on the constraint planes entered in Item 8Z (for ITOC = 1), Item 8DD (for ITOC = 2), and/or Item 8GG (for ITOC = 3) if ITOC1 = 0.

The next item in Figure 6-12 is the inverse-moment matrix defined near the top of page 3-9 of Reference 4. The version of this matrix that is listed in this figure was computed in the previous search step, and the values in Figure 6-12 are a repetition of the values provided toward the end of the output for that step (see Figure 6-14 and associated discussion below). The size of the inverse-moment matrix, 3x3 for the case shown in Figure 6-12, corresponds to the number of active constraints. This matrix, as well as all subsequent search-module printed output except for flutter speeds and the new store parameters, are given in terms of scaled variables.

The flutter-speed change listed next is with respect to the value for the previous analysis cycle. This quantity is listed for the first entry to the search module as well as for the second and subsequent entries, but for the first entry, the printed result is meaningless in that it is with respect to the arbitrarily high initial value specified for VNFW in Item 8K of the vibration-analysis-module input data.

The reader is reminded that, as indicated in Items 8A, 8J, and 8K in Subsection 5.2.2 of this report, a restart run requires certain changes to the primary input-data file in addition to the use of the restart file as an input via TAPE47.

7 - REFERENCES

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2. Chipman, R. R., and Malone, J. B., "Study of a Method for Determining Critical Store Configurations for Wing-Store Flutter", Grumman Aerospace Corporation Report No. ADCR-76-1, September 1976. (Final report for Naval Air Systems Command contract N00019-76-C-0160)

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APPENDIX A

NASTRAN/ESP INTERFACE

A.1 - COSMIC NASTRAN

As was discussed briefly in Subsection 5.1, one form in which dynamics-model matrices may be read in ESP is that provided by the OUTPUT2 routine in the COSMIC version of NASTRAN (see Reference 8, pages 5.5-24 through 5.5-27). In this interface as presently implemented, any matrices that are to be obtained from COSMIC NASTRAN must be written via the same output unit. In the control-statement sequence, the local-file designator for this unit is UT1, and, in the required additional DMAP statements, the unit designator should be set to 11.

It is noted parenthetically that an interface in which matrices are written to separate files (via different output units) would have provided the user with a greater freedom of choice in selecting combinations of ESP input matrices. However, at least for the CDC April 1984 COSMIC NASTRAN release, for which the present interface was developed, the code as delivered provides for only one output unit in conjunction with OUTPUT2. A Fortran modification could be introduced to obtain the more general capability described in Reference 8. However, it was judged that most installations would probably be using the program as received from COSMIC, and that users at these installations would prefer to restrict their OUTPUT2 usage to a single unit rather than change, or request a change to, their original NASTRAN source code.

It is noted also that difficulty was encountered in obtaining results from OUTPUT2 using release 17.7 of COSMIC NASTRAN. Thus far, the procedure described herein has been used successfully only with the April 1984 release.

An illustrative control-statement sequence for executing the April 1984 release of COSMIC NASTRAN on the NADC Central Computer System is shown in Figure A-1. In addition to containing the time parameter, the JOB card

```
NASTRAN,TXXXX,STNOS.
ACCOUNT,UUUUUU,PPPPPP.
GET,DDDDDDD.
DEFINE,UT1=KMDM.
GET,NAST484/UN=SYSTEM.
BEGIN,,NAST484.
RFL,160000.
REDUCE(-).
LINK1,DDDDDDD.
```

Figure A-1 - Typical Control-Card Sequence for COSMIC NASTRAN Run to Prepare OUTPUT2 File for ESP.

specifies execution via the NOS operating system. Execution is initiated via the LINK1 statement, in which the second term is the input data file.

The permanent file name KMDM, shown in conjunction with local file UT1 in Figure A-1, is intended as a reminder of the required matrix order in the OUTPUT2 file. As will be seen from the subsequent discussion of the additional DMAP statements, each letter in the OUTPUT2 permanent-file name is the first letter of a DMAP name that has been assigned herein to one of the four matrices used by ESP:

- o K - flexibility matrix
- o M - dynamic mass matrix
- o D - rigid-body-displacement matrix
- o M - plug mass matrix

Note however that, as indicated in Subsection 5.1, not all ESP input matrices must be read from the same source, and therefore the OUTPUT2 file should not necessarily include all four of the matrices listed.

Figure A-2 shows a representative set of DMAP modifications to Rigid Format 3 (Normal Mode Analysis) to obtain a file of the desired ESP matrices via OUTPUT2. The statements to be added to the Executive Control Deck are shown in part (a) of the figure. Part (b) shows these statements in the context of the original DMAP sequence, so that the relationship of the alters to the rigid format in which they are inserted can be seen without having to refer either to the printed DMAP sequence in Reference 8 (pages 3.4-1 through 3.4-6) or to a listing obtained from a NASTRAN execution using a DIAG 14 Executive Control card. For a more complete understanding of the relationship between the alters and the original DMAP sequence, the reader may wish to consult the description of the DMAP operations in Rigid Format 3 given on pages 3.4-7 through 3.4-11 of Reference 8.

A key consideration in determining the DMAP alters for providing the ESP matrices is the set of units used in the NASTRAN analysis. Independent of the source of the needed matrices, the units must be as specified in Subsection 5.1. For the case illustrated in Figure A-2, the Bulk Data was in the same units as those used in ESP, and a PARAM WTMASS card had been included to

```
ALTER 66
SOLVE      KLL,/KLLI/ $
MATPRN     KLLI,,,,// $
PARAMR     //*DIV*/V,N,RECWTM/1.0/C,Y,WTMASS $
PARAMR     //*COMPLEX*//V,N,RECWTM/0.0/V,N,RECWTMC $
ADD        MLL,/MLLW/V,N,RECWTMC $
ADD        MRR,/MRRW/V,N,RECWTMC $
MATPRN     MLLW,MRRW,,,// $
ALTER 68
MATPRN     DM,,,,// $
OUTPUT2    KLLI,MLLW,DM,MRRW,//-1/11 $
OUTPUT2    ,,,,//-9/11 $
```

(a) Additions to Executive Control Deck

```
                         •
                         •
                         •
62   SMP1       USET,KFF,,,/GO,KAA,KOO,LOO,,,,, $
63   SMP2       USET,GO,MFF/MAA $
64   LABEL .    LBL5 $
65   COND       LBL6,REACT $
66   RBMG1      USET,KAA,MAA/KLL,KLR,KRR,MLL,MLR,MRR $
66   SOLVE      KLL,/KLLI/ $
66   MATPRN     KLLI,,,,// $
66   PARAMR     //*DIV*/V,N,RECWTM/1.0/C,Y,WTMASS $
66   PARAMR     //*COMPLEX*//'',N,RECWTM/0.0/V,N,RECWTMC $
66   ADD        MLL,/MLLW/V,N,RECWTMC $
66   ADD        MRR,/MRRW/V,N,RECWTMC $
66   MATPRN     MLLW,MRRW,,,// $
67   RBMG2      KLL/LLL $
68   RBMG3      LLL,KLR,KRR/DM $
68   MATPRN     DM,,,,// $
68   OUTPUT2    KLLI,MLLW,DM,MRRW,//-1/11 $
68   OUTPUT2    ,,,,//-9/11 $
69   RBMG4      DM,MLL,MLR,MRR/MR $
70   LABEL      LBL6 $
                         •
                         •
                         •
```

(b) Modified Rigid-Format-3 Listing

Figure A-2 - Illustrative Modifications to COSMIC NASTRAN Rigid Format 3 (Normal Mode Analysis) to Obtain Desired ESP Matrices via OUTPUT2

convert the weight data to mass units within NASTRAN. To return to the weight units, the reciprocal of the WTMASS parameter (RECWTM) was computed, and this, when converted to the required complex form, was used to multiply the dynamic mass matrix (MLL) and the plug mass matrix (MRR).

To be consistent with the procedure for reading the COSMIC NASTRAN matrices in ESP, the first parameter in the OUTPUT2 calling sequence (see Reference 8, page 5.5-24) must be -1 when writing the desired matrices. The second parameter, which is the output unit number, will, as noted previously, usually be 11 for CDC COSMIC NASTRAN. The third parameter is not needed, and is therefore omitted in the example shown in the figure. Following the use of OUTPUT2 to write the matrices, a second OUTPUT2 statement is included (according to instructions in Reference 8) to write an end-of-file mark.

As a final comment on obtaining ESP matrices from COSMIC NASTRAN, and MSC NASTRAN as well, it is noted that the dynamics idealization used must be chosen so as to be consistent with the ESP interpolation procedure. Specifically, the dynamics grid points must lie on a set of spanwise-oriented lines as illustrated in Reference 1, Volume I, page 86.

To complete the discussion of the interface between COSMIC NASTRAN and ESP, a sample of the printed output that is obtained from ESP when matrices are read from an OUTPUT2 file is shown in Figure A-3. The printing of the flexibility and dynamic mass matrices is controlled by KLUEV(7) and KLUEV(8), respectively (see Subsection 5.2.2); the rigid-body-displacement matrix and the plug mass matrix are always printed. The matrix name shown in the ESP listing is taken from the name used in the OUTPUT2 DMAP statement.

A.2 - MSC NASTRAN

The interface between the MacNeal-Schwendler Corporation (MSC) version of NASTRAN and ESP parallels that developed for COSMIC NASTRAN except for a few variations. First, to provide greater freedom of choice in selecting combinations of ESP input matrices, the four desired matrices are assumed to be written by MSC NASTRAN via OUTPUT4 to three different output units rather than

```
READING COSMIC NASTRAN MATRIX DM
   NUMBER OF COLUMNS =    3
   NUMBER OF ROWS    = 130

     READING COLUMN    1
     NUMBER OF ROWS READ = 130

 1.0000E+00  3.5441E-14 -5.4770E-13  1.0000E+00  3.4475E-14
 5.2374E-15 -2.3313E-13  1.0000E+00  9.4279E-16 -4.5516E-14
 2.2774E-10  1.0000E+00 -1.2897E-11  2.2778E-10  1.0000E+00
 1.0000E+00 -1.2897E-11  2.2781E-10  4.1930E-07 -5.6440E-09
-4.6411E-12  2.9308E-07 -2.2524E-09 -3.0687E-10 -9.7966E-14
-2.6587E-10 -3.2529E-11  4.8359E-10 -2.1033E-10 -6.1954E-11
-1.4661E-11  5.9053E-10 -4.5631E-11 -4.9853E-12  6.0109E-10  • • •
-1.2362E-10  7.1660E-11  1.6474E-09 -5.2270E-02 -1.5679E-12
-3.8408E-11  2.6592E-09 -4.2439E-10 -3.8408E-11  1.1875E-08
-4.6407E-02 -5.5957E-10 -4.6407E-02  5.2812E-10 -4.6407E-02
-4.6407E-02 -1.5956E-10 -3.3057E-02  1.2539E-09 -3.3057E-02
 8.2763E-09 -5.4285E-11  6.3358E-09 -5.7732E-11  4.5312E-09
 3.1170E-09 -1.2079E-10  3.4353E-09 -1.7612E-10  4.6702E-09

     READING COLUMN    2
     NUMBER OF ROWS READ = 130

-6.3810E+00  1.0000E+00  1.5607E-12 -3.7010E+00  1.0000E+00
 1.0000E+00  5.1404E-13  1.6552E-12  1.0000E+00  9.2646E-14
 1.6479E-09 -1.5791E-07  1.0000E+00  1.6479E-09 -2.0545E-07
-2.8628E-07  1.0000E+00  1.6479E-09  3.1751E-06 -2.1575E+02
 1.0000E+00  2.1656E-06 -1.8100E+02  8.8518E-08  1.0000E+00  • • •
 1.1644E-07  1.0000E+00 -1.2600E+02  1.0246E-07  1.0000E+00
 1.0000E+00 -6.6430E+01  4.6917E-08  1.0000E+00 -4.9675E+01
 1.9330E-08  9.9863E-01 -5.2340E-02 -8.8280E+01 -3.0605E-08
 1.0000E+00 -2.2900E+02 -9.8517E-08  1.0000E+00 -2.2900E+02
                          •
                          •
                          •
```

Figure A-3 - Typical ESP Listing Obtained When Reading COSMIC NASTRAN OUTPUT2 File

only one as with COSMIC NASTRAN. Three units should be used, rather than four, because the plug mass matrix is considered to be appended to the file containing the dynamic mass matrix.

A second difference is that the ESP interface with MSC NASTRAN has been written to take advantage of the two matrix sparseness options that are available in the OUTPUT4 routine (see Reference 9, pages 5.4-91 through 5.4-92a). The usually sparse dynamic mass matrix is assumed to be transferred using the sparse option, and the transfer of the other three matrices is done via the nonsparse option.

A typical set of MSC-NASTRAN DMAP alter statements for Rigid Format 3 in CDC Release 63, April 1983, is shown in Figure A-4, part (a). To show the context in which these statements are used, portions of the resulting modified DMAP listing are given in part (b) of this figure. A comparison of the OUTPUT4 statements contained in the figure with the OUTPUT4 description given in Reference 9 illustrates the points made in the previous paragraph.

Figure A-5 shows the form of the printed output from ESP when reading a matrix from an OUTPUT4 file. The "type" of the MSC NASTRAN matrices (see Reference 9, page 5.4-2a) is required by ESP to be real, single-precision, and, to provide a check that this rule has been followed, the numerical index for the type is listed from the first record of each OUTPUT4 file. The header information for each column, which is obtained from the beginning of the OUTPUT4 record for that column, provides additional information for checking purposes related to the data-condensation features in OUTPUT4.

```
ALTER 181
SOLVE     KLL,/KLLI/ $
MATPRN    KLLI// $
OUTPUT4   KLLI//-3/11 $
ALTER 212
MATPRN    DM// $
OUTPUT4   DM//-3/12 $
ALTER 250
PARAMR    //DIV/V,N,RECWTM/1.0/WTMASS $
PARAMR    //COMPLEX//RECWTM/0.0/V,N,RECWTMC $
ADD       MLL,/MLLW/V,N,RECWTMC $
ADD       MRR,/MRRW/V,N,RECWTMC $
MATPRN    MLLW,MRRW// $
OUTPUT4   MLLW//-1/-13 $
OUTPUT4   MRRW//-2/13 $
```

(a) Additions to Executive Control Deck

```
                  •
                  •
                  •
181  UPARTN   USET,KTT/KLL,,KLR,KRR/T/L/R $
181  SOLVE    KLL,/KLLI/ $
181  MATPRN   KLLI// $
181  OUTPUT4  KLLI//-3/11 $
                  •
                  •
                  •
212  RBMG3    LLL,,KLR,KRR/DM $
212  MATPRN   DM// $
212  OUTPUT4  DM//-3/12 $
                  •
                  •
                  •
250  UPARTN   USET,MTT/MLL,,MLR,MRR/T/L/R $
250  PARAMR   //DIV/V,N,RECWTM/1.0/WTMASS $
250  PARAMR   //COMPLEX//RECWTM/0.0/V,N,RECWTMC $
250  ADD      MLL,/MLLW/V,N,RECWTMC $
250  ADD      MRR,/MRRW/V,N,RECWTMC $
250  MATPRN   MLLW,MRRW// $
250  OUTPUT4  MLLW//-1/-13 $
250  OUTPUT4  MRRW//-2/13 $
251  RBMG4    DM,MLL,MLR,MRR/MR $
                  •
                  •
                  •
```

(b) Modified Rigid-Format-3 Listing

Figure A-4 - Illustrative Modifications to MSC NASTRAN Rigid Format 3 (Normal Mode Analysis) to Obtain Desired ESP Matrices via OUTPUT4

```
READING MSC NASTRAN MATRIX KLLW
   TYPE = 1
   NUMBER OF COLUMNS = 130
   NUMBER OF ROWS    = 130

     READING COLUMN    1
     FIRST NONZERO ROW =    1
     NUMBER OF ROWS READ =    3

 7.3290E+01 -8.2305E+01  6.0757E+02  0.          0.          0.          0.          0.          0.          0.
 0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
 0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
                                   •
                                   •
                                   •

     READING COLUMN   91
     FIRST NONZERO ROW =   16
     NUMBER OF ROWS READ =   85

 0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
 0.          0.          0.          0.          0.          3.9684E+00  3.8977E+01 -4.8454E+02  0.          0.
 0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
 0.          0.          0.          1.4382E-01 -1.9749E-04  2.0631E-03  1.9979E-03 -1.8109E+00  4.3883E-03  4.0272E-03
-1.4271E-02  1.1170E+01 -3.3429E-03  1.8047E-03 -8.7390E-03 -1.9212E+01  4.0875E-01  9.5569E-01  1.6260E+00 -9.5752E-01
-1.3383E+01 -6.6552E+00  2.0846E+00  1.0171E+01  1.1979E+01 -2.2448E+00  1.2601E+01  1.0748E+01 -6.8473E-01 -2.1452E+02
 5.7179E-01 -2.8038E-05  5.4838E-03  7.4630E-04 -9.0796E-02 -1.5810E+01  1.5813E+00 -9.5186E+01  6.7748E+01  2.1272E-01
-7.5018E+01 -9.1747E-01 -6.1058E-01  1.7951E-02 -2.1772E+02  0.          0.          0.          0.          0.
 0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
 1.2368E+01  3.5164E+01 -2.9340E+00  1.1068E+00 -1.4052E-01 -8.9227E+00  7.5203E-01 -3.4959E-01 -2.8099E-01  1.1615E-01
 4.3522E-01  2.6667E+00  2.3495E-03 -6.5229E-03 -5.2894E-03 -6.3914E-03  3.5985E-03 -2.0895E-03 -3.0779E-03  5.2388E-04
 8.7359E-02  5.1766E-01  1.2026E+00  6.9957E+00 -1.6117E-01 -3.7032E-02  6.8618E-02  2.6424E-02 -2.0121E-02  2.8073E-02
 1.5563E-03  4.0986E-03 -2.7933E-03 -1.0779E-02  9.9288E-06 -1.0450E-03 -9.3545E-05  6.1627E-04  2.5753E-04  2.1808E-04

     READING COLUMN   92
     FIRST NONZERO ROW =   16
     NUMBER OF ROWS READ =   85

 0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
 0.          0.          0.          0.          0.         -4.0213E-01 -1.2789E+01  5.1448E+02  0.          0.
                                   •
                                   •
                                   •
```

Figure A-5 - Typical ESP Listing Obtained When Reading MSC NASTRAN OUTPUT4 File

APPENDIX B

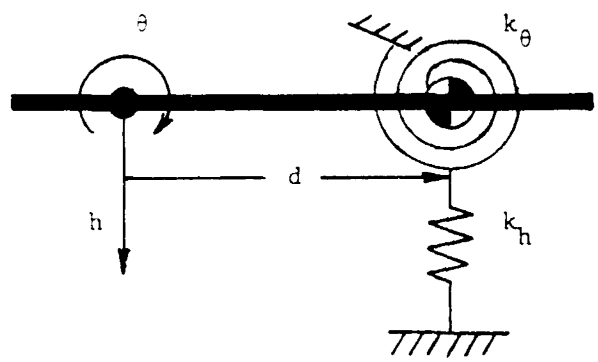
IMPLEMENTATION OF CAPABILITY FOR RIGID-BODY MODES

Since a capability for representing free-free modes was contained in the FASTOP code from which the original version of ESP was developed, a major portion of the capability for including rigid-body modes in the output from the vibration-analysis module could be implemented by simply obtaining the mode shapes themselves from the transformation matrix from relative to absolute coordinates.

With the mode shapes being available, the rigid-body generalized-mass terms could be readily calculated as an integral part of the calculation for the the flexible-mode generalized masses. The rigid-body portion of the generalized-mass matrix would generally contain off-diagonal terms, however, since the ignorable coordinates, or "plug" degrees of freedom (see Reference 1, Volume I, Section 7, pages 48 and 49), would generally not be coincident with the airplane center of gravity.

With the introduction of a capability for user specification of zero-airspeed rigid-body frequencies (see page 3-2), a procedure for calculating rigid-body elements in the generalized-stiffness matrix was required. It was judged most desirable for the user-specified rigid-body frequencies to apply to uncoupled modes, i.e., to modes in which the rotations are about the airplane center of gravity. With this approach, the effective rigid-body springs would be located at the center of gravity, and the generalized-stiffness matrix, in terms of modes defined by the plug degrees of freedom, would be similar to the generalized-mass matrix in that it too would contain off-diagonal terms.

In the discussion that follows, the elements of the generalized-stiffness matrix are developed in terms of the elements of the generalized-mass matrix and the specified natural frequencies for a rigid-body system with one translation mode and one rotation mode. Thereafter, expressions are given for the more general modal combinations associated with either symmetric (longitudinal) or antisymmetric (lateral) motions.



If the system shown above has mass m and moment of inertia I about the center of gravity, the equations of motion may be written as

$$\begin{bmatrix} m & md \\ m & I + md^2 \end{bmatrix} \begin{Bmatrix} \ddot{h} \\ \ddot{\theta} \end{Bmatrix} + \begin{bmatrix} k_h & k_h d \\ k_h d & k_\theta + k_h d^2 \end{bmatrix} \begin{Bmatrix} h \\ \theta \end{Bmatrix} = 0 . \qquad \text{(B-1)}$$

From inspection of the figure, or from a solution of the equations of motion, the natural frequencies of this system are

$$\omega_h = (k_h/m)^{1/2} , \ \omega_\theta = (k_\theta/I)^{1/2} . \qquad \text{(B-2)}$$

To develop the desired relationships between the generalized-stiffness matrix elements and the generalized-mass matrix elements and the natural frequencies, Eq. (B-1) is first rewritten as follows:

$$\begin{bmatrix} M_{hh} & M_{h\theta} \\ M_{\theta h} & M_{\theta\theta} \end{bmatrix} \begin{Bmatrix} \ddot{h} \\ \ddot{\theta} \end{Bmatrix} + \begin{bmatrix} K_{hh} & K_{h\theta} \\ K_{\theta h} & K_{\theta\theta} \end{bmatrix} \begin{Bmatrix} h \\ \theta \end{Bmatrix} = 0 . \qquad \text{(B-3)}$$

By comparing Eqs. (B-1) and B-3), it is seen that d may be written as

$$d = M_{h\theta}/M_{hh} . \qquad \text{(B-4)}$$

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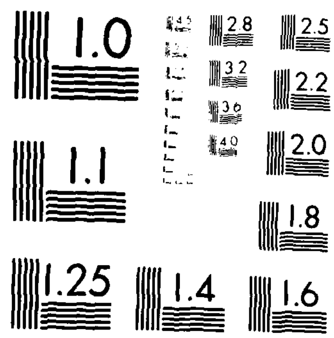

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Now, by using all of the above equations, three of the generalized-stiffness/generalized-mass/natural-frequency relationships may be written immediately as

$$K_{hh} = M_{hh}\,\omega_h^2 , \tag{B-5}$$

$$K_{h\theta} = M_{h\theta}\,\omega_h^2 , \tag{B-6}$$

$$K_{\theta h} = M_{\theta h}\,\omega_h^2 = K_{h\theta} . \tag{B-7}$$

The expression for $K_{\theta\theta}$ requires some algebraic manipulation. First, an expression for I is formed by comparing Eqs. (B-1) and (B-3) and substituting Eq. (B-4):

$$I = M_{\theta\theta} - \frac{M_{h\theta}^2}{M_{hh}} . \tag{B-8}$$

Substituting this result into the second of Eqs. (B-2) yields

$$k_\theta = \left(M_{\theta\theta} - \frac{M_{h\theta}^2}{M_{hh}}\right)\omega_\theta^2 . \tag{B-9}$$

Finally, after equating stiffness elements in Eqs. (B-1) and (B-3), and utilizing Eqs. (B-4), (B-6), and (B-9), the desired expression for $K_{\theta\theta}$ is obtained:

$$\begin{aligned} K_{\theta\theta} &= \left(M_{\theta\theta} - \frac{M_{h\theta}^2}{M_{hh}}\right)\omega_\theta^2 + \left(\frac{M_{h\theta}^2}{M_{hh}}\right)\omega_h^2 \\ &= M_{\theta\theta}\,\omega_\theta^2 + \left(\frac{M_{h\theta}^2}{M_{hh}}\right)\left(\omega_h^2 - \omega_\theta^2\right). \end{aligned} \tag{B-10}$$

For the general symmetric case consisting of fore-and-aft translation, vertical translation, and pitch, which will be denoted here by the subscripts 1, 2, and 3, respectively, the generalized stiffness elements are

$$K_{11} = M_{11}\,\omega_1^2\,, \tag{B-11}$$

$$K_{12} = K_{21} = 0\,, \tag{B-12}$$

$$K_{13} = K_{31} = M_{13}\,\omega_1^2\,, \tag{B-13}$$

$$K_{22} = M_{22}\,\omega_2^2\,, \tag{B-14}$$

$$K_{23} = K_{32} = M_{23}\,\omega_2^2\,, \tag{B-15}$$

$$K_{33} = M_{33}\,\omega_3^2 + \sum_{i=1}^{2}\left[\left(\frac{M_{i3}^2}{M_{ii}}\right)\left(\omega_i^2 - \omega_3^2\right)\right]. \tag{B-16}$$

For the general antisymmetric case consisting of lateral translation, roll, and yaw, denoted by the subscripts 1, 2, and 3, respectively, the generalized stiffness elements are:

$$K_{11} = M_{11}\,\omega_1^2\,, \tag{B-17}$$

$$K_{12} = K_{21} = M_{12}\,\omega_1^2\,, \tag{B-18}$$

$$K_{13} = K_{31} = M_{13}\,\omega_1^2\,, \tag{B-19}$$

$$K_{23} = K_{32} = M_{23}\,\omega_1^2\,, \tag{B-20}$$

$$K_{22} = M_{22}\,\omega_2^2 + \left(\frac{M_{12}^2}{M_{11}}\right)\left(\omega_1^2 - \omega_2^2\right), \tag{B-21}$$

$$K_{33} = M_{33}\,\omega_3^2 + \left(\frac{M_{13}^2}{M_{11}}\right)\left(\omega_1^2 - \omega_3^2\right). \tag{B-22}$$

The calculation of the rigid-body generalized stiffness elements in ESP is performed via Eqs. (B-11) through (B-22).

APPENDIX C

DEFINITION OF CONSTRAINT PLANES

For the results obtained from ESP to have the most practical significance, it is desirable that a minimum-flutter-speed point in the store-parameter search space be close to an actual store configuration. This in turn makes it desirable to define the search space in such a manner that regions with no or few store points are minimized. One step that can be taken toward meeting this objective is to allow isolated extreme store-parameter combinations to fall outside the search space, and then analyze these points individually. Beyond that, however, the degree of refinement of the search-space boundaries will usually be dependent primarily on the amount of effort devoted to the constraint-plane definition.

C.1 - FULLY INDEPENDENT SEARCH VARIABLES

The simplest approach to the definition of constraint planes is to assume that the range of the search for each store parameter is independent of the value of every other parameter. With this approach, only an upper and a lower bound for each search variable need be specified, and the search space, when scaled according to the suggestions in Item 8I, Subsection 5.2.2, will then be a unit multi-dimensional cube oriented such that each search-variable axis is normal to one pair of parallel cube faces. Items 8P, 8R, and 8S, which are the data items associated with the general method of constraint-plane definition in ESP, will then take on the following values:

- The number of constraint planes, MSTAR, which determines the number of columns in the array G(J,I), will be twice the number of search variables, NPARM.
- Each unit normal vector, constituting one column of length NPARM in the array G(J,I), will have only one search-space component, J, that is nonzero. For the upper-bound constraints, that nonzero component will be +1.C, and, for the lower-bound constraints, it will be -1.0. A sample G(J,I) array for fully independent search variables is shown in Figure C-1(a).

$$
\begin{array}{cc}
 & \text{MSTAR} = (2*\text{NPARM}) \\
\begin{array}{c}\text{NPARM}\\ =5\end{array} &
\begin{bmatrix}
1.0 & & & & & -1.0 & & & & \\
 & 1.0 & & & & & -1.0 & & & \\
 & & 1.0 & & & & & -1.0 & & \\
 & & & 1.0 & & & & & -1.0 & \\
 & & & & 1.0 & & & & & -1.0
\end{bmatrix}
\end{array}
$$

(a) Fully Independent Search Variables (5 variables shown)

$$
\begin{array}{cc}
 & \text{MSTAR} = (2*4) + (1*2) \\
\begin{array}{c}\text{NPARM}\\ =(2*2)\\ +1\end{array} &
\begin{bmatrix}
G(1,1) & G(1,2) & & G(1,4) & & & & & \\
G(2,1) & & G(2,3) & G(2,4) & & & & & \\
 & & & & G(3,5) & \cdots & G(3,8) & & \\
 & & & & G(4,5) & \cdots & G(4,8) & & \\
 & & & & & & & 1.0 & -1.0
\end{bmatrix}
\end{array}
$$

(b) Partial Two-Dimensional Search-Range Dependency (1 fully independent variable and 2 store stations with two-dimensional dependency represented by 4-sided polygons)

$$
\begin{array}{cc}
 & \text{MSTAR} = 8 \\
\begin{array}{c}\text{NPARM}\\ = 3\end{array} &
\begin{bmatrix}
G(1,1) & & G(1,3) & & G(1,5) & G(1,6) & G(1,7) & \\
 & G(2,2) & & G(2,4) & & G(2,6) & G(2,7) & G(2,8) \\
 & & G(3,3) & & G(3,5) & & & G(3,8)
\end{bmatrix}
\end{array}
$$

(c) Three-Dimensional Search-Range Dependency (1 store station with dependency represented by polyhedron with 8 faces)

Figure C-1 - Illustrative Unit-Normal-Vector Arrays, G(J,I)

- In Item 8S, the scaled distance, B, to each constraint, I, will be measured along the search-space axis corresponding to the single nonzero component of the associated unit normal vector.

C.2 - VARIABLES WITH TWO-DIMENSIONAL SEARCH-RANGE DEPENDENCY

In general, an effort toward some refinement of the search space will be warranted, and, if the refinement is limited to two variables (e.g., mass and pitch inertia) at each station, it is easily introduced in many situations. A key consideration is whether the range of store parameters at one station can be assumed to be unaffected by the stores at other stations. If so, the constraint equations for each station can be developed independently, and the two variables at each station for which the search ranges are to be mutually dependent will constitute a two-dimensional space such as the schematic shown in Figure 3-1, page 3-2, Reference 4. Any other variables at each station, for which no search-space refinement is to be introduced, will be independent of each other and also independent of the two variables involved in the refinement.

The determination of the contributions to G(J,I) and B(I) from each two-dimensional space may be accomplished using either of two approaches. A primarily graphical approach involves: (1) drawing an outward normal from the scaled search space at each polygon side, and then determining its direction cosines (components of the unit normal vector); and (2) measuring the scaled normal distance from the origin to each polygon side or extension thereof. Alternatively, the scaled polygon vertices may be used to develop an equation for each polygon side; then these equations may be manipulated into the form given in Eq. (3-1), page 3-1, Reference 4, from which the desired results are immediately available.

The data in Items 8P, 8R, and 8S may now be obtained as a combination of the results for the individual store stations:

- MSTAR, which corresponds to the number of columns in the array G(J,I), will be the sum of two contributions: (1) the sum of the number of sides associated with the polygons for the two store parameters at each station with mutually dependent search ranges; and

(2) twice the number of additional mutually independent variables (as in Subsection C.1).

- The columns of G(J,I), which are composite unit normal vectors considering all search variables at all store stations, will in general have two nonzero elements for those vectors associated with a polygon side. Vectors associated with constraints for mutually independent variables will have one nonzero component (as in Subsection C.1). A G(J,I) array illustrating this combination is shown in Figure C-1(b).
- The array B(I) will be comprised in part of elements equal to the distances to the polygon sides and in part of elements similar to those in Subsection C.1.

C.3 - VARIABLES WITH THREE-DIMENSIONAL SEARCH-RANGE DEPENDENCY

If the refinement of a store-parameter space is to be carried a step further, such that the search ranges of three variables are considered mutually dependent, the previous discussion might lead to the conclusion that three-dimensional modeling is required. However, as is discussed and illustrated in Subsection 7.2 of Reference 4, an alternative procedure is to define the desired enclosing polyhedron for a three-dimensional space (e.g., mass, M, pitch inertia, I, and longitudinal center of gravity, x) by constructing constraint lines in three two-dimensional spaces ((M,I), (M,x), and (x,I)) successively.

An important advantage of this approach, other than facilitating the definition of the three-dimensional search boundary, is the fact that each face of the resulting polyhedron appears as a line in at least one of the three two-dimensional spaces. Thus, the unit normal vectors to be provided in the G(J,I) array will each consist of no more than two nonzero components which can be determined from two-dimensional plots exactly as described in Subsection C.2.

The data in Items 8P, 8R, and 8S of Subsection 5.2 will again consist of a combination of the data for individual stations. As in the previous subsection, fully independent search variables may be added to those having

dependency, and, if desired, two-dimensional dependency may be assumed at one store station and three-dimensional dependency at another. For this more general situation:

- o The number of constraint equations, MSTAR, will be the sum of: (1) the total number of polyhedron faces; (2) the total number of polygon sides; and (3) twice the total number of mutually independent search variables.
- o The unit normal vectors, which comprise the columns of G(J,I), will again have at most two nonzero components. However, the two nonzero components for a polyhedron face may correspond to any two of the three search parameters associated with that polyhedron, and, therefore, as illustrated in Figure C-1(c), the two nonzero elements in a column of G(J,I) will not necessarily be contiguous.
- o Since the polyhedron faces for the variables with three-dimensional dependency may be viewed as a polygon side in a two-dimensional space, the B(I) array here will be similar to that in Subsection C.2.

C.4 - VARIABLES WITH HIGH-ORDER SEARCH-RANGE DEPENDENCY

When a further search-space refinement is deemed necessary, such that the search ranges of four or more store parameters are mutually dependent, there is not now to the author's knowledge a procedure for readily defining the constraint hyperplanes. Perhaps the best ultimate solution would be a geometric optimization program that would provide the arrangement of a specified number of hyperplanes that minimizes the interior volume containing the set of actual store-inventory points. Until such a capability is available, perhaps the best approach to use, when it is important to consider four or more parameters to have mutually dependent search ranges, is to perform searches in two (or possibly more) successive three-parameter spaces: The three parameters that are judged to be most important from a flutter-speed point of view would be included in the first search space, and then the minimum-flutter-speed point(s) found from the first search would be used as starting point(s) for a search in a second space that would include other store parameters as variables.

As has been noted in Subsection 5.2.2, one special case of a four-parameter problem that can be readily accommodated at present is the situation in which pitch and yaw inertia are considered to vary in an identical manner (KCONST = 0 in Item 8J). The number of variables with mutually dependent search ranges is now reduced by one from a program-logic viewpoint, so that the approach of Subsection C.3 is directly applicable. Even when pitch and yaw inertia do vary independently to a significant extent, the "slaving" approach will probably constitute a good first approximation. A follow-up search can then be done, as discussed in the previous paragraph, in a space containing pitch and yaw inertias as separate variables.

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